Discussion Paper on Advancing Essential Fish Habitat Descriptions and Maps for the 2022 5-year Review

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Abstract: Councils and NMFS are required to review the essential fish habitat (EFH) components of Fishery Management Plans (FMPs) and revise or amend these components based on available information at least every five years (50 CFR 600.815(a)(10)) in what is referred to as an EFH 5-year Review. The study presented in this Discussion Paper demonstrates advances in EFH component 1 descriptions and identification (maps) based on refinements to the habitat-based species distribution modeling (SDM) approach to mapping EFH that was established in the 2017 EFH 5-year Review[8]. All of the SDM ensembles constructed for FMP species in the eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) in this present work describe and map EFH Level 2 (habitat related abundance), meeting a key objective of the EFH Research Plan for Alaska. For early juvenile life stages in the GOA, SDMs describe and map EFH Level 1 (distribution) for the first time. Another objective of the Research Plan is met by introducing maps for a subset of species with EFH Level 3 information (habitat related vital rates) for the first time. In this study, EFH is described and mapped for 32 North Pacific groundfish species in the EBS, 25 in the AI, 42 in the GOA across up to three life stages. In addition, EFH is described and mapped for five crabs in the EBS, two crabs in the AI, and octopus in all three regions. A total of 229 new or revised EFH Level 1, 2, and 3 maps for 211 individual species' life stages and 7 stock complexes are available for the 2022 EFH 5-year Review. The SDMs provided insight into the environmental conditions affecting patterns of species distribution and abundance, where influential covariates varied by region, species, and life stage. The type of SDM used in 2017 had a large effect on the model performance and EFH areas in comparison to the 2022 ensembles; in the majority of cases, 2022 ensemble performance demonstrated clear improvements over the 2017 SDMs. The maps and descriptions here present the best available science to form a basis for assessing anthropogenic impacts to habitats in Alaska and are extensible to other fishery and ecosystem management information needs. Future research is recommended, including developing methods for combining disparate data sources to expand spatial and seasonal coverage of Alaska species distribution and abundance as well as increasing the scope of EFH research to address rapidly changing environmental conditions in the region. This document also reports the comprehensive and iterative review process that the present work has undergone as part of the 2022 EFH 5-year Review while providing the complete 2022 SDM-based EFH methods and results herein and as attachments.

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EXECUTIVE SUMMARY

The objective of an essential fish habitat (EFH) 5-year Review is to review the ten EFH components of Fishery Management Plans (FMPs) and revise or amend EFH components as warranted based on available information (50 CFR 600.815(a)(10)). The EFH regulations outline ten components for the EFH contents of FMPs. For component 1, FMPs are required to describe and identify EFH in text that clearly states the habitats or habitat types determined to be EFH for each life stage of the managed species and to include maps that display the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found. Additionally, FMPs must demonstrate that the best scientific information available was used in the description and identification of EFH, consistent with national standard 2 (50 CFR 600.815(a)(1)(i)(B)).

This Discussion Paper and attachments present the new information that NMFS is developing under EFH component 1, the description and identification of EFH (50 CFR 600.815(a)(1)), for the 2022 5-year Review. These documents describe research using species distribution models (SDMs) to describe and map EFH for life stages of North Pacific groundfishes and crabs and provide the details of the iterative review process that this body of work has undergone to date in the 2022 5-year Review. The new EFH descriptions and maps are provided to the SSC to assist in their evaluation of new information for EFH component 1 and will support the fishing effects analysis of EFH component 2 at a subsequent stage of the 2022 5-year Review.

Component 1 EFH Descriptions and Identification

Component 1 descriptions and identification of EFH consist of written summaries, tables, and maps in the FMPs or their appendices. The EFH regulations provide an approach to organize the information necessary to describe and identify EFH (50 CFR 600.815(a)(1)(iii)). When designating EFH, the Council should strive to describe and identify EFH information in the FMPs at the highest level possible (50 CFR 600.815(a)(1)(iii)(B))—

Level 1: Distribution data are available for some or all portions of the geographic range of the species.

Level 2: Habitat-related densities or relative abundance of the species are available.

Level 3: Growth, reproduction, or survival rates within habitats are available.

Level 4: Production rates by habitat are available. [Not available at this time.]

Further, the EFH regulations state that Councils should strive to describe habitat based on the highest level of detail. **The study presented in this Discussion Paper uses this approach to explain the SDM information and maps in terms of EFH Levels 1 and 2, and for the first time, Level 3 as available.**

2017 EFH 5-year Review

The North Pacific Fishery Management (Council) completed the last EFH 5-year Review in 2017 (Simpson et al. 2017). For that 5-year Review, a new approach to EFH component 1 was developed that used SDMs to map distribution and relative abundance across different habitats for individual life stages of species in Alaska FMPs, including Groundfish of the Bering Sea and Aleutian Islands Management Area (BSAI FMP), Groundfish of the Gulf of Alaska (GOA FMP), and Bering Sea/Aleutian Islands King and Tanner Crabs (Crab FMP). New information was also reviewed for the FMP for Salmon Fisheries in the EEZ off Alaska that included quantitative model-based maps (Echave et al. 2012) and for the FMP for Fish Resources of the Arctic Management Area that included maps of species distribution from surveys.

Three types of SDMs were used to model the distribution and relative abundance of species' life stages in the BSAI, GOA, and Crab FMPs, including a generalized additive model (GAM), hurdle GAM, and maximum entropy model (MaxEnt), using 4th root transformed catch-per-unit-effort (CPUE) data from NMFS Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys. The type of SDM applied was determined *a priori* by the prevalence of a species' life stage in the survey catch.

The 2017 SDM approach to EFH was a significant advancement, providing new EFH Level 1 (distribution) and Level 2 (habitat-related density or abundance) information for groundfish and crabs and substantially improving the EFH maps. The new and revised EFH descriptions and maps were combined with advancements in understanding the impacts of fishing and non-fishing activities on EFH and other new information in the 2017 5-year Review (Simpson et al. 2017). Accordingly, the Council and NMFS revised the EFH sections of these FMPs to incorporate the results of 2017 5-year Review and the EFH Omnibus Amendment package was approved on May 31, 2018 (83 FR 31340, July 5, 2018).

2022 EFH 5-year Review

The 2022 EFH 5-year Review is an iterative review process. Review of current and new EFH information by experts and other stakeholders is an important part of an EFH 5-year Review for our region and serves to strengthen the contributing research and the EFH 5-year Review process overall.

Since the 2017 EFH 5-year Review, NMFS has worked to improve the EFH descriptions and maps and the results of this work are presented in this Discussion Paper. During the 2022 EFH 5-year Review process to date, the studies contributing new information for EFH component 1 have been reviewed by the SSC, Plan Teams, stock assessment authors, species experts, and other stakeholders. EFH analysts have incorporated feedback from each of these sources into the work products for component 1. This Discussion Paper provides an overview of the stages of the iterative process by which NMFS and the Council are reviewing the EFH component 1 descriptions and maps for the 2022 EFH 5-year Review, with a focus on expert review by stock assessment authors (hereafter referred to as SAs)—

- NMFS and the Council launched the 2022 EFH 5-year Review in April 2019 with a presentation by NMFS to the Ecosystem Committee of the preliminary plan for review of the ten EFH components in the Council's FMPs.
- The SSC in June 2020 and a joint meeting of the Groundfish Plan Teams (JGPT) in September 2020 provided input regarding a presentation by NMFS on proposed methods, progress to date, and planned research products to support the new EFH component 1 information for the 2022 5-year Review (Pirtle et al. 2020)[9].
- In January 2021, NMFS EFH component 1 analysts and senior stock assessment scientists convened a summit of SAs to co-develop the process for the SA review of EFH component 1, which was an innovation of NMFS Alaska's approach to the 2022 EFH 5-year Review.
- NMFS presented the 2022 EFH 5-year Review Plan to the SSC in April 2021, when EFH component 1 analysts responded to the SSC and Plan Team input received in 2020, by providing an update on methods and revised draft results examples. The 2022 5-year Review Plan was also presented to the Crab Plan Team in May 2021, including draft SDM ensemble results for crabs.
- The SA review of the new draft SDM ensemble methods, results, EFH maps, and current EFH component 1 information in the FMPs was conducted from May to September 1 2021. Just following the completion of the SA review, EFH component 1 analysts presented a clear response plan to the JGPT in September 2021.

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[9] June 2020 EFH Component 1 Discussion Paper and Presentation to SSC are available at https://www.npfmc.org/efh-distribution/

- Between September 2021 and January 2022, EFH component 1 analysts addressed all reviewer concerns, incorporated input to revise the draft methods, updated the results, and submitted three regional NOAA Technical Memoranda to the NMFS publication process (Attachments 3-5). We, the EFH component 1 analysts, are grateful for the large amount of effort that the individual SAs and other species experts brought to bear to improve this work.
- The stock assessment author review of EFH component 1 is discussed in detail in the Report of Stock Assessment Author Review of EFH Components 1 and 7 for the 2022 EFH 5-year Review (Attachment 1). EFH analysts presented a draft of Attachment 1 to the JGPT in November, 2021 and the report has since been finalized for SSC review in February 2022.
- EFH component 1 analyst responses to requests and recommendations by the SSC and Plan Teams from the meeting minutes for the stages of the iterative review of EFH component 1 are provided in Appendix 1 Table A1.1.

New SDM ensemble-based EFH maps for the 2022 EFH 5-year Review

The Alaska EFH Research Plan that guides research to meet EFH mandates in Alaska was revised following the completion of the 2017 5-year Review (Sigler et al. 2017). This revision incorporated additional research and information needs along with the five long-term EFH research goals that have guided EFH research in Alaska since 2005. The revised plan provided two-specific research objectives to advance EFH information for Alaska in the intervening 5 years leading up to the 2022 5-year Review:

1. Develop EFH Level 1 (distribution) or Level 2 (habitat-related densities or abundance) for life stages and areas where missing.
2. Raise EFH information from Level 1 or Level 2 to Level 3 (habitat-related growth, reproduction, or survival rates (i.e., vital rates)).

NMFS Alaska Region (AKR) and AFSC funded several studies to accomplish Alaska EFH Research Plan research objectives. **This Discussion Paper presents new research from the following study available for the 2022 EFH 5-year Review—**

Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species, Ned Laman[10], Jodi Pirtle[11], Jeremy Harris[12], Margaret Siple[10], Chris Rooper[13], Tom Hurst[14], and Christina Conrath[15], funded by the Alaska EFH Research Plan in FY19, FY20, and FY21 (hereafter referred to as **Laman et al. study**) (Chapter 3).

The purpose of this study is to describe and map EFH for federally managed North Pacific groundfish and crab species in the EBS, AI, and GOA using SDMs and to advance levels of EFH information for the life stages of those species. This study is guided by the Alaska EFH Research Plan (Sigler et al. 2017) research priority 1 to characterize habitat utilization and productivity using the best available scientific information to accomplish the two specific research objectives of the revised plan.

The Laman et al. study demonstrates a **revised SDM ensemble EFH approach** for the 2022 EFH 5-year Review, where EFH is described and mapped for 32 North Pacific groundfish species in the EBS, 25 in the AI, 42 in the GOA across up to three life stages. In addition, EFH is described and mapped for five crabs in the EBS, two crabs in the AI, and octopus in all three regions. The ensembles describing and

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mapping EFH in this study advance EFH information levels and refine EFH area maps for North Pacific species' life stages from none to Level 1 and from none or Level 1 to Level 2. This study also applies habitat-related vital rates from other studies to the ensemble outcomes to describe and map EFH Level 3 for the first time. The EFH descriptions and maps from this study comprise the bulk of new EFH component 1 information available for the 2022 EFH 5-year Review and also support the EFH component 2 fishing effects analysis[16].

The Laman et al. study's approach to using SDM-based ensembles for mapping EFH is described and contrasted with the SDM EFH approach of the 2017 EFH 5-year Review in the Discussion Paper Methods section and Table 1. Highlights from the Laman et al. study approach are developing several data updates and modeling refinements, introducing EFH Level 3, and advancing EFH information levels, including—

- Expanding the SDM approach from the 2017 5-year EFH Review to include up to five constituent SDMs in an ensemble that provides a robust modeling framework for future EFH Reviews (three SDMs were applied in 2017 and a single SDM was selected *a priori* for each species' life stage based on prevalence in the bottom trawl surveys);
- Refining our methodology by modeling numerical abundance instead of 4th root transformed CPUE facilitated skill testing (lowest cross-validated root mean square error; RMSE) to identify the best fitting models for inclusion and weighting in the ensemble and improved the interpretability of model results (i.e., predicting numbers of animals instead of a heavily derived abundance index);
- Demonstrating the incorporation of new sources of species response data for the settled early juvenile life stage of groundfishes in the GOA added nearshore areas not previously modeled and allowed us to evaluate EFH for this critical life stage for the first time;
- Updating habitat covariates applied as independent predictors in the ensembles provided the opportunity to expand our observed temperature data set with an additional five years of AFSC RACE-GAP summer trawl survey bottom temperature observations, include recently modeled bottom temperature data from the coastal GOA regional ocean modeling system 3 km grid (applied to early juvenile SDMs only), update the GOA bathymetry and seafloor slope covariates, include additional derived seafloor terrain metrics in all regions, develop and include a seafloor rockiness metric for the AI and GOA, and to incorporate the most recent substrate data in the Bering Sea;
- Enhancing existing data sets (both response and predictor variables) with the addition of five recent years of survey results from the AFSC RACE-GAP summer bottom trawl surveys (2015–2019) extended our temporal coverage in the EBS to 38 years (1982-2019), in the AI to 29 years (1991-2019), and to 27 years in the GOA (1993-2019);
- Updating length-based life stage definitions for North Pacific groundfish species in the SDM ensembles based on updated maturity schedules or life stages definitions documented in the recent scientific literature tailored our abundance predictions to the best available scientific information and increased the number of life stages we could model; and

[16] New and revised EFH descriptions and maps from three additional studies developing new EFH component 1 information for the 2022 EFH 5-year Review will be presented to SSC for review in June 2022(T). SSC reviewed the draft methods and preliminary results from these studies in June 2020 (https://www.npfmc.org/efh-distribution/). The EFH maps by these studies do not support the EFH component 2 fishing effects analysis.

- Extending EFH to include settled early juvenile life stages allowed us to model this critical ontogenetic phase for North Pacific groundfish species in the EBS, AI, and GOA for the first time.

The results of applying this revised SDM ensemble approach for mapping EFH are presented in the Discussion Paper as **three regional results case studies demonstrating EFH Level 2 maps with bridging comparisons between the 2017 and 2022 EFH maps.** These case studies present the full set of results for one species' life stage in each region and have been selected as examples of EFH area decreasing (arrowtooth flounder adults in the eastern Bering Sea), increasing (golden king crab life stages in the Aleutian Islands), and remaining relatively even (Pacific cod adults in the Gulf of Alaska) between 2017 and 2022.

Pacific cod settled early juveniles in the Gulf of Alaska are presented demonstrating EFH Level 1 and Level 3 maps for this life stage in that region.

The complete set of results for all species' life stages modeled in the three regions are provided in the attached NMFS Technical Memoranda (Attachments 3-5) and summarized in Appendix 2 (5.2) Comparisons between the 2017 SDMs and 2022 ensembles and EFH maps are in Appendix 3 (5.3) and Attachment 2 is the full set of the 2017 and 2022 EFH map overlay figures (e.g., as presented in the regional case study bridging figures). Expanded reporting of additional performance metrics considered by the Laman et al. study and requested for consideration by the SSC are in Appendix 4 (5.4). A Synthesis subsection concludes the Laman et al. Results section of the Discussion Paper and draws from the results summaries and comparisons in the Appendices.

One valuable feature of habitat-related SDMs is that they can provide insight into the environmental conditions that affect patterns of species distribution and abundance. The three most influential (highest percent contribution to the deviance explained by the SDM or ensemble) covariates for each species' life stage in the 2022 EFH 5-year Review are reported in Table A2.1 and in the Synthesis subsection of the Results. **Summarized across all species' life stages modeled, the most influential covariates were—**

- Geographic location and bottom depth. One or both of these were present in the top three contributing covariates for over 90% of the SDMs and ensembles.
- Bottom currents and bottom temperature were less influential, but each appeared in the top three for approximately 25% of the SDMs and ensembles.
- Tidal maximum, bathymetric position index (BPI), sediment grainsize (*phi*), rockiness, and sponge presence were occasionally top contributors, and appeared in the top three in approximately 5–15% of SDMs and ensembles.

The most influential covariates also varied by region. In the AI, bottom currents were relatively more influential and bottom temperature was relatively less influential. In the Bering Sea, temperature was more influential and tidal maximum was less influential. In the GOA, sponge presence and BPI were relatively more influential than in other regions.

In progress studies developing temporally dynamic SDM methods for mapping EFH (e.g., Barnes et al. *in review*) will help improve understanding of how species' habitat-related distribution, abundance, vital rates, and population productivity (EFH Levels 1-4) are influenced by the rapidly changing environment in our region, which has the potential to help NMFS become more climate responsive to the EFH regulations and EBFM.

In comparing the 2017 SDMs and 2022 ensembles (e.g., Table A3.2), it is apparent that the type of model used in 2017 had a large effect on the performance metrics and calculated EFH areas. **In the majority of cases, the performance metrics from the 2022 ensembles demonstrated clear improvements over the 2017 SDMs. The 2022 ensemble showed improvement in—**

- Lowest cross-validated root mean square error (RMSE) in 88% of models,
- Spearman's correlation (ρ) in 69% of models,
- Area under the receiver operating characteristic curve (AUC) in 52% of models,
- Poisson deviance explained (PDE) in 99% of models.
- In other cases, where clear improvement was not observed, the difference between the models was usually small, and in no instance was a decline observed across all metrics.
- Approximately 25% of ensembles in the present work predicted EFH areas larger by 100% or more; in almost all of these cases the 2017 SDM was hGAM.
- Approximately 18% of ensembles resulted in EFH areas that were smaller by at least half; in each of these cases the 2017 SDM was a MaxEnt model.

The ensemble modeling approach to describe EFH in the present work provides several advantages. Certain classes of SDMs have tendencies to over- or under-predict distribution and abundance (i.e., Maxent and hGAM). Ensemble modeling essentially averages the predictions from multiple, best-performing constituent SDMs, which can provide abundance predictions that are more representative of habitat-related distribution and abundance than those produced by single SDMs in isolation.

Updates to data and methods used during the 2022 EFH 5-year Review have resulted in advancements in EFH Level for many species' life stages (Table A3.1). EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence, EFH Level 2 with a model that can also predict abundance or density, and EFH Level 3 where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **The following EFH Level advancements are available for the 2022 5-year Review—**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 has not changed. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2022 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2022, although the data and methods were updated and revised in the 2022 ensemble approach to mapping EFH.
- For the first time, EFH Level 2 models were combined for member species of each of 7 stock complexes in the BSAI (4) and GOA (3) groundfish FMPs to represent the EFH of member

species where a model was not possible at this time (i.e., fewer than 50 positive survey catches were available) (50 CFR 600.815(a)(1)(iv)(E)).

A total of 229 new and revised EFH descriptions and maps for the BSAI, GOA, and Crab FMPs are available for the 2022 EFH 5-year Review—

- New EFH Level 1 descriptions and maps for settled early juvenile life stages in the GOA FMP (11).
- New and revised EFH Level 2 descriptions maps for the BSAI (115), GOA (76), and Crab (7) FMPs (200).
- New EFH Level 2 descriptions and maps for stock complexes as a proxy for member species where a model was not possible at this time for the BSAI (6) and GOA (4) FMPs (10).
- New EFH Level 3 descriptions maps for settled early juvenile life stages (BSAI (2) and GOA (6) FMPs = 8).

While completing the body of work presented in the Discussion Paper, and through the iterative review process of the 2022 EFH 5-year Review to date, EFH component 1 analysts identified refinements and recommendations that could be considered for future EFH 5-year Reviews. These recommendations are in three categories:

1. Prioritize and improve EFH for select species (data and modeling);
2. Increasing the scope and applicability of EFH research; and
3. Improving process and communication.

A Future Recommendations section is included in this Discussion Paper and in each regional Technical Memorandum, which provides more detailed descriptions of the research and collaborative pathways the EFH component 1 analysts are recommending (Attachments 3-5).

Importance of the Alaska Species Distribution Models

The study presented in this Discussion Paper, and three additional studies in development for the 2022 EFH 5-year Review, advance the SDM EFH approach of the 2017 5-year Review and offer new information and techniques, including a new SDM ensemble modeling approach to mapping EFH. This work demonstrates advances to EFH descriptions and maps for many groundfish and crab species in the BSAI and GOA, including new and revised EFH Level 1 and 2, and for the first time EFH Level 3 information.

This body of work represents a significant advancement of the SDM approach for mapping EFH from that of the 2017 EFH 5-year Review. The ensemble approach developed here, along with the other data and modeling refinements described, will provide a robust and flexible framework for the development of EFH descriptions and maps for future EFH 5-year Reviews. In addition, the ensembles described here provide valuable information that can be extended to stock assessment and other EBFM information needs in our region.

As of this document draft and since in June 2020, we have received input on progress to date for the draft SDM ensemble methods, results, and EFH maps in a comprehensive and iterative review process from the SSC, Crab Plan Team, Groundfish Plan Teams, stock assessment authors, species experts, and the public. We look forward to sharing the body of work presented here with the SSC in February 2022, the three additional studies with the SSC in June 2022(T), and the 2022 EFH 5-year Review Summary Report with the Council in October 2022(T).

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1 INTRODUCTION

1.1 Essential Fish Habitat Overview

Essential fish habitat (EFH) is defined as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (50 CFR 600.10). The EFH Final Rule requires that the National Marine Fisheries Service (NMFS) and Fishery Management Councils (Councils) describe and identify EFH for managed species, minimize to the extent practicable the adverse effects of fishing and other anthropogenic activities on EFH, and identify actions to encourage the conservation and enhancement of EFH. Federal agencies that authorize, fund, or undertake actions that may adversely affect EFH must consult with NMFS, and NMFS must provide conservation recommendations to federal and state agencies regarding these actions. As part of this mandate, EFH text descriptions and maps are necessary for each life stage of species in a Fishery Management Plan (FMP) (EFH component 1, descriptions and identification) (50 CFR 600.815) with an overarching consideration that the science related to this effort meets the standards of best available scientific information (NMFS National Standard 2 – Scientific Information 50 CFR 600.315).

The North Pacific Fishery Management Council (Council) described EFH for its FMPs in 1999 with an environmental assessment that also outlined human-induced effects on EFH. In 2000, a legal challenge of the EFH provisions nation-wide resulted in a reevaluation of EFH information by all Councils. In 2005, the Alaska Region and Council completed a more comprehensive EFH description and effects analysis in an environmental impact statement (EIS)[17].

Councils and NMFS are required to review the EFH components of FMPs and revise or amend these components based on available information at least every five years (50 CFR 600.815(a)(10)). The six Council FMPs are:

- Groundfish of the Bering Sea and Aleutian Islands Management Area (BSAI FMP)
- Groundfish of the Gulf of Alaska (GOA FMP)
- Bering Sea/Aleutian Islands King and Tanner Crabs (Crab FMP)
- Scallop Fishery off Alaska (Scallop FMP)
- Salmon Fisheries in the EEZ off Alaska (Salmon FMP)
- Fish Resources of the Arctic (Arctic FMP).

The Council conducted its first EFH 5-year Review and updated the EFH information for all six FMPs in 2010 (77 FR 66564, 11/06/2012). The Council concluded its second EFH 5-year Review in 2017 and updated EFH information for five FMPs (83 FR 31340, 7/05/2018, Simpson et al. 2017) (see section 2017 EFH 5-year Review).

For the 2022 Review, NMFS and the Council are evaluating the EFH components in the Council's FMPs. NMFS has prioritized the seven EFH components in bold for a comprehensive review:

1. **EFH descriptions and identification**
2. **Fishing activities that may adversely affect EFH**
3. Non-MSA fishing activities that may adversely affect EFH
4. **Non-fishing activities that may adversely affect EFH**
5. Cumulative impacts analysis
6. **EFH conservation and enhancement recommendations**
7. **Prey species list and locations**
8. Habitat Areas of Particular Concern (HAPC) identification
9. **Research and information needs**

[17] https://www.fisheries.noaa.gov/resource/document/final-environmental-impact-statement-essential-fish-habitat-identification-and

10. Review EFH every 5 years.

A comprehensive review of each of the seven EFH components prioritized by NMFS and the Council will be presented to the Council in a summary report at the conclusion of the review in October 2022(T). If the Council chooses to update its FMPs based on the report, FMP amendments will be prepared along with the appropriate analytical documents through the normal Council process.

1.2 Component 1 EFH Descriptions and Identification

Component 1 descriptions and identification of EFH consists of written summaries, tables, and maps in the FMPs or appendices. The EFH regulations provide an approach to organize the information necessary to describe and identify EFH (50 CFR 600.815(a)(1)(iii)). When designating EFH, the Council should strive to describe and identify EFH information in the FMPs at the highest level possible (50 CFR 600.815(a)(1)(iii)(B))—

Level 1: Distribution data are available for some or all portions of the geographic range of the species.

Level 2: Habitat-related densities or relative abundance of the species are available.

Level 3: Growth, reproduction, or survival rates within habitats are available.

Level 4: Production rates by habitat are available. [Not available at this time.]

1.2.1 2017 EFH 5-year Review

Prior to the 2017 EFH 5-year Review, EFH component 1 (descriptions and identification) in the six FMPs was the distribution of species' life stages and maps based on survey results and observed catch. A new approach to develop species-specific habitat information for EFH component 1 was developed for the 2017 EFH 5-year Review that used species distribution models (SDMs) to describe and map the habitat-related distribution and abundance for many species of groundfish in the BSAI and GOA FMPs and crabs in the Crab FMP, where data existed for egg, larval, juvenile, and adult life history stages in four seasons. SDM results were provided as text and maps that described and identified the attributes and location of EFH. The SDM EFH approach of the 2017 Review is discussed in detail in the 2017 EFH Summary Report (Simpson et al. 2017), three NOAA Technical Memoranda (Laman et al. 2017, Turner et al. 2017, Rooney et al. 2018), and a peer-reviewed publication (Laman et al. 2018). New information was also reviewed for the Salmon FMP that included quantitative model-based maps (Echave et al. 2012) and for the Arctic FMP that included maps of species distribution from surveys (Simpson et al. 2017).

As an outcome of the 2017 Review, the Council adopted SDMs to describe and identify EFH (Laman et al. 2018) and updated EFH information levels and maps for species life history stages (Simpson et al 2017). EFH maps are available on the Alaska[18] and National[19] EFH Mappers, the NMFS Alaska Region EFH webpage[20], and in the six FMPs[21]. The SDMs developed during the 2017 Review resulted in more quantitative, precise descriptions and identification of EFH in the FMPs, and met the recommendations in the MSA to use the best available scientific information to define EFH (50 CFR 600.315).

[18] https://www.fisheries.noaa.gov/resource/map/alaska-essential-fish-habitat-efh-mapper
[19] https://www.habitat.noaa.gov/protection/efh/efhmapper/index.html
[20] https://www.fisheries.noaa.gov/alaska/habitat-conservation/essential-fish-habitat-efh-alaska
[21] https://www.fisheries.noaa.gov/rules-and-announcements/plans-and-agreements?title=&management_area%5BAlaska%5D=Alaska&sort_by=title

1.2.2 2022 EFH 5-year Review

The Alaska EFH Research Plan has guided research to meet EFH mandates in Alaska since 2005 (AFSC 2006, Sigler et al. 2012). Revisions of this plan accompany the EFH 5-year reviews that summarize the status of EFH research (EFH component 9, research and information needs), which provides a basis to determine future research directions. Building on the progress of the 2017 EFH 5-year Review, the Alaska EFH Research Plan was revised (Sigler et al. 2017), incorporating additional research and information needs along with the five long-term EFH research goals (Sigler et al. 2017). The revised plan provided two-specific research objectives to advance EFH information for Alaska in the intervening 5 years leading up to the 2022 5-year Review:

1. Develop EFH Level 1 (distribution) or Level 2 (habitat-related densities or abundance) information for life stages and areas where missing; and
2. Raise EFH information from Level 1 or Level 2 to Level 3 (i.e., vital rates like habitat-related growth, reproduction, or survival).

NMFS Alaska Region (AKR) and AFSC funded several studies to accomplish Alaska EFH Research Plan research objectives. **This Discussion Paper presents new research from the following study available for the 2022 EFH 5-year Review—**

Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species, Ned Laman[22], Jodi Pirtle[23], Jeremy Harris[24], Margaret Siple[10], Chris Rooper[25], Tom Hurst[26], and Christina Conrath[27], funded by the Alaska EFH Research Plan in FY19, FY20, and FY21 (hereafter referred to as **Laman et al. study**) (Chapter 3).

The Laman et al. study demonstrates the **revised SDM ensemble EFH approach** for the 2022 EFH 5-year Review utilizing the best available scientific information. The ensembles describing and mapping EFH in this study advance EFH information levels and refine EFH area maps for North Pacific species' life stages from none to Level 1 and from none or Level 1 to Level 2. This study also applies habitat-related vital rates from other studies to the ensemble outcomes to describe and map EFH Level 3 for the first time. The EFH descriptions and maps from this study comprise the bulk of new EFH component 1 information available for the 2022 EFH 5-year Review and also support the EFH component 2 fishing effects analysis.

This Discussion Paper and attachments introduce the Laman et al. study, presenting the complete methods and results, including case studies for species' life stages in the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA. Regional methods details and the full set of species' life stage results are in three Technical Memoranda (Attachments 3-5). The iterative review process that this study has undergone to date is described (Chapter 2), where Attachment 1 is the stock assessment author review of the study draft methods and results with EFH analyst responses. EFH analyst responses to SSC and Plan Team input on the methods and results of this study during the iterative 2022 EFH 5-year Review process are in Appendix 1 (5.1).

Three other studies developing new EFH component 1 information for the 2022 5-year Review are scheduled to be presented to SSC in June 2022(T) and are not presented in this Discussion Paper:

[22] GAP, AFSC, Seattle, WA
[23] HCD, NMFS AKR, Juneau, AK
[24] GAP, AFSC, Lynker, Seattle, WA
[25] DFO, Nanaimo, BC, Canada
[26] FBEP, AFSC, Newport, OR
[27] GAP, AFSC, Kodiak, AK

- **Model-Based Essential Fish Habitat Descriptions for Fish Resources of the Arctic Management Area** by Jennifer Marsh[28], Jodi Pirtle[29], Franz Mueter[30], Jeremy Harris[31], and Alison Deary[32], funded by BOEM FY19/20.
    - Arctic EFH maps are not currently based on SDMs. This study has developed SDMs for life stages of Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*) and snow crab (*Chionoecetes opilio*), including EFH Level 1, 2, and 3 descriptions and maps, to improve the quality of Arctic species EFH information. This study will also provide comparisons of species distribution and EFH area in warm and cold years.
- **Optimal Thermal Habitat of Juvenile Walleye Pollock (*Gadus chalcogrammus*) in the Gulf of Alaska** by Ben Laurel[33], Louise Copeman[33], Tom Hurst[33], Jodi Pirtle[29], and Georgina Gibson[34], funded by Alaska EFH Research Plan FY17/18/19.
    - This study incorporates field sampling, laboratory experiments, and SDMs to develop EFH Level 3 descriptions and maps. This study has developed a winter energy loss rate as a metric of physiological condition and energetic status for early juvenile walleye pollock and EFH level 3 maps for walleye pollock in the GOA.
- **Novel Approach to Estimate Habitat-Related Survival Rates for Early Life History Stages using Individual-Based Models** by Kalei Shotwell[35], Buck Stockhausen[36], Georgina Gibson[34], Jodi Pirtle[29], Chris Rooper[37], and Alison Deary[32], funded by Alaska EFH Research Plan FY18/19.
    - This integrated modeling study applies biophysical individual-based models (IBMs), SDMs, spawning locations and biomass, and vital rates to develop EFH Level 2 and 3 descriptions and maps for sablefish (*Anoplopoma fimbria*) and Pacific cod (*Gadus macrocephalus*) pelagic early life history stages in the GOA, providing a novel alternative to develop EFH information for life history stages that are difficult to comprehensively sample by field surveys alone.

This body of work for EFH component 1 available for the 2022 EFH 5-year Review is innovative and inclusive of many contributors that are developing new habitat related distribution, abundance, and vital rate information for North Pacific species.

In addition to supporting our EFH mandates, the new species and life stage specific habitat information presented for the 2022 EFH 5-year Review is extensible to stock assessment and other ecosystem-based fisheries management (EBFM) information needs for our region. The Ecosystem and Socioeconomic Profiles (ESP) in the Stock Assessment and Fishery Evaluation (SAFE) Reports include SDMs developed for EFH component 1 in the 2017 EFH 5-year Review (Rooney et al. 2018) and the GOA Integrated Ecosystem Research Program (Pirtle et al. 2019) (e.g., GOA walleye pollock; Shotwell et al. 2019). Recent studies have also applied these SDMs and contemporary extensions to demonstrate a synthesis of life history information for groundfish species (Doyle et al. 2018), develop example stock-

[28] University of Alaska Fairbanks (UAF), HCD, NMFS AKR, Anchorage, AK
[29] HCD, NMFS AKR, Juneau, AK
[30] UAF, Juneau, AK
[31] GAP, AFSC, Lynker, Seattle, WA
[32] ECO FOCI, AFSC, Seattle, WA
[33] FBEP, AFSC, Newport, OR
[34] UAF, Fairbanks, AK
[35] REFM, AFSC, Juneau, AK
[36] REFM, AFSC, Seattle, WA
[37] DFO, Nanaimo, BC, Canada

specific indicators for the ESPs (Shotwell et al. *in press*), develop high resolution SDMs as a case study for EFH species and their prey in the nearshore (Grüss et al. 2021), test hypotheses about groundfish recruitment processes in the GOA (Goldstein et al. 2020), and identify spatial-temporal stock structure in the EBS under future climate scenarios (Rooper et al. 2021) and most recently with new temporally dynamic SDMs (Barnes et al. *in review*). Several milestones of the Alaska EBFM Roadmap Implementation Plan (NMFS 2018) reference actions related to habitat science and EFH. In these examples, information and SDMs developed for EFH, such as those presented in this Discussion Paper, are extended in a meaningful context to further support fishery and ecosystem management in our region.

The study presented in this Discussion Paper, and the three additional studies in development for the 2022 EFH 5-year Review, advance the SDM EFH approach of the 2017 5-year Review and offer new information and techniques, including a new SDM ensemble modeling approach to mapping EFH. This work demonstrates advances to EFH descriptions and maps for many species in the BSAI, GOA, and Crab FMPs, including new and revised EFH Level 1 and 2, and for the first time EFH Level 3. As of this document draft and beginning in June 2020, we have received input on progress to date for the draft SDM ensemble methods, results, and EFH maps in a comprehensive and iterative review process from the SSC, Crab Plan Team, Groundfish Plan Team, stock assessment authors, species experts, and the public. We look forward to sharing the body of work presented here with the SSC in February 2022, the three additional studies with the SSC in June 2022(T), and the 2022 EFH 5-year Review Summary Report with the Council in October 2022(T).

2 ITERATIVE REVIEW

Review of current and new EFH information by experts and other stakeholders is an important part of an EFH 5-year Review for our region and serves to strengthen the contributing research and the EFH 5-year Review process overall. Since the 2017 EFH 5-year Review, NMFS has worked to improve the EFH descriptions and maps in the EBS, AI, and GOA and new versions are now available for the 2022 Review.

During the 2022 EFH 5-year Review process to date, the studies contributing new information for EFH component 1 have been reviewed by the SSC, Plan Teams, stock assessment authors, species experts, and other stakeholders. As the Council process is public, materials provided for review to the Council bodies have also been available to the public and valuable public testimony was received at each meeting. EFH analysts have incorporated feedback from each of these sources into the work products for component 1. This section provides an overview of the iterative process by which NMFS and the Council is reviewing the EFH component 1 descriptions and maps for the 2022 EFH 5-year Review, with a focus on expert review by stock assessment authors (hereafter SAs).

2.1 Iterative Review Process for EFH Component 1 in the 2022 5-year Review

This section provides a timeline of the iterative review process to date for EFH component 1, descriptions and maps, in the 2022 EFH 5-year Review (Figure 1). NMFS and the Council launched the 2022 EFH 5-year Review in April 2019 with a presentation by NMFS to the Ecosystem Committee (EC) of the preliminary plan for review of the EFH components of FMPs. The iterative review timeline of EFH component 1 begins with the SSC review in June 2020 and proceeds through the JGPT review in November 2021, which is the last stage immediately preceding Crab Plan Team (CPT), EC, and SSC reviews in January and February 2022. Details of the SSC and Plan Team input and EFH analyst responses at each stage of the review process are provided in Appendix 1 Table A1.1 and referenced throughout this document.

June 2020: SSC reviewed proposed methods and preliminary results examples and provided input regarding study methods, progress to date, and planned research products to support the new EFH component 1 information for the 2022 Review. Following this first SSC review, EFH analysts took steps to revise their approach in response to this input (Table A1.1 items 1a-l).

September 2020: JGPT reviewed proposed methods and preliminary results examples and provided input regarding study methods, progress to date, and planned research products to support the new EFH component 1 information for the 2022 Review. Following this first JGPT review, EFH analysts took steps to further revise their approach in response to this input and then proceeded to develop the draft results for further evaluation (Table A1.1 items 2a-c).

January 2021: NMFS AKR and AFSC EFH analysts, and senior stock assessment scientists convened a summit of SAs to develop the process for the SA review of EFH components 1 and 7. At this meeting, SAs were informed of the EFH 5-year Review process, tools in development to provide new EFH component 1 (descriptions and identification) and component 7 (prey species) information, and their role. EFH analysts and SAs co-developed an approach and timeline for the SA review of these two EFH components for the 2022 Review. Agreement was reached on the timeline to coordinate the review (i.e., of current FMP EFH text and maps and new SDM ensemble EFH draft methods and results) with existing stock assessment timing and workload, agreeing on a review period from May 15 to September 1 2021. Agreement was also reached on the content and nature of the review, which was to provide an extensive, expert peer review of the current information available for components 1 and 7 and, in particular, the new information for component 1. SAs reviewed EFH component 1 and 7 EFH information on the same stocks for which they authored assessments. Finally, SAs led a discussion on connections between EFH components 1 and 7 research and stock assessment to identify opportunities to strengthen work products and support shared management needs for stock assessment, EFH, and EBFM.

April 2021: A paper describing the 2022 EFH 5-year Review Plan was presented to the SSC and Council. The paper described the ten EFH components, work related to the components and the FMPs, and what types of new information will be included in the EFH 5-year Review summary report. The SSC highlighted the importance of SA review in their minutes from April 2021: “The SSC considers consultation with assessment authors to be a critical link in evaluating model configuration and output, and was pleased to hear the EFH team was involving assessment authors early in the EFH review process.” SSC provided additional guidance (Table A1.1 items 3a-j).

May 2021: The 2022 EFH 5-year Review Plan was presented to the CPT in May 2021. The presentation included SDM ensemble methods and preliminary results for crabs. The presentation also provided the opportunity for the CPT members to participate in the review process as species experts along with the SAs. All species except for Tanner crab had at least two SA reviewers to offer edits, updates, and suggestions. The SA-species reviewer partnership for crabs was new for this review and offered more opportunities for expert feedback. The CPT requested that the crab SAs and experts receive the EFH components 1 and 7 review materials first to accommodate the timing of the crab stock assessments. The EFH analyst team agreed and provided crab reviewers with review materials in May 2021 (Table A1.1 items 4a-b).

May to September 2021: The agreed upon SA review period was from May to September 1. New EFH component 1 information was provided to the SAs for their review, revisions, and recommendations. During this time, EFH analysts conducted their own internal review of the draft methods and results. Following the SA review in September, EFH analysts began to review the SA review input and prepared for the September JGPT meeting to provide a first overview of the SA review results, and plan to address concerns and revise the draft results for subsequent SSC review in February 2022.

September 2021: The joint meeting of the Groundfish Plan Teams in September, 2021 was an opportunity for the EFH analysts to meet with the JGPT and groundfish SA community following their review that concluded on September 1, just prior to this meeting. At the meeting, the EFH analysts provided a preliminary summary the SA reviews received as well as the analysis team’s responses to the leading concerns and questions from the SAs. This included an explanation of replacing the single ensemble fit metric, Spearman's rho-squared, with three conventional metrics to more comprehensively assess ensemble performance. Model performance was reevaluated for all SDM ensembles and revised in the species results chapters provided in the three draft Technical Memoranda for the EBS, AI, and GOA that have been submitted to the NMFS publication process (Attachments 3-5).

EFH analysts clearly communicated at the meeting that they would follow up with all SAs who expressed concerns in their reviews to answer questions and communicate any necessary revisions, including updated model performance metrics and other results (Table A1.1 items 5a-g). Although EFH analysts had been following up with SAs as their reviews were returned over the summer, SAs with concerns that affected their confidence in the models and outcomes were prioritized for more in-depth follow-up. EFH analysts communicated at the JGPT September meeting that they would make revisions as needed and provide opportunity for the SAs to review the revised species chapters should they be interested prior to the SSC February Meeting when the full set of revised methods, results, and 2017/2022 EFH area comparisons would be shared with the SSC for review. See Attachment 1 for details on this communication process.

October 2021: The SSC reviewed the JGPT September meeting report, which included the Team's report on the EFH presentation. Although SSC review of EFH component 1 was not planned for the October meeting, SSC provided additional and extensive requests for component 1 that the EFH analysts incorporated into this document and attachments for SSC review in February 2022 (Table A1.1 items 6a-n).

November 2021: The JGPT November meeting was an opportunity for EFH analysts to provide an overview of the iterative review process for EFH component 1 in the 2022 Review to date and to share the final stages of the SA review, including EFH analyst responses to all reviewing SAs. EFH analysts provided a draft of the Report of Stock Assessment Author Review of EFH Components 1 and 7 for the 2022 EFH 5-year Review as an attachment for this meeting that posted on November 9, 2021 to provide time to review the draft report prior to the presentation on November 15, 2021. From the meeting's minutes: "The Teams thanked the EFH analysts for the development and application of the EFH models, the responsiveness to stock assessment author reviews, and for the detailed report describing the review process." (Table A1.1 item 7a). The next steps of the 2022 Review process are presentations to the CPT and EC in January 2022 and to the SSC in February 2022.

2.2 Stock Assessment Author Review of EFH Component 1

Review by SAs and species experts is a critical element of the iterative EFH 5-year Review process and serves to strengthen the evaluation. Reviewers are provided guidance that their recommendations should be based on their review of the current and new EFH information and the guidance of National Standard 2 and the EFH Final Rule to describe EFH based on the best scientific information available at the highest level of detail possible (50 CFR 600.815(a)(1)(iii)(B)).

For the 2017 Review, each SA was asked to review current FMP EFH component 1 information for each species or species complex for which they have responsibility. SAs were asked to review and update, if appropriate, EFH text descriptions, EFH levels, habitat association tables, habitat-related life history information including prey of EFH species (component 7), and relevant literature. SAs were provided with the new SDM maps developed for the 2017 Review and compared the new maps to the old maps from the 2010 EFH Review. Following the SA and subsequent SSC review of EFH component 1, SAs were provided output from the Fishing Effects model and asked to evaluate the effects of fishing on their stocks, following a method developed during the 2017 Review for EFH component 2 fishing activities that may adversely affect EFH. This information was summarized and presented to the Plan Teams and the Council for the 2017 Review.

The 2022 EFH 5-year Review provided an opportunity to improve on the process of the 2017 Review of EFH components 1 and 7. NMFS started the SA review with a workshop in January 2021 and concluded the process by presenting the SA Review Report to the SSC in February 2022 (Attachment 1). Improvements to the process in the 2022 Review, included reaching agreement with SAs regarding the timing and expectations of the document review period, achieved in the January 2021 workshop, and providing SAs with access to both the draft methods and preliminary results for the EFH component 1 SDMs in their review. SA review of the EFH component 2 fishing effects analysis has been arranged separately and under a different process, which should be very similar to the 2017 EFH 5-year Review.

The details of the SA review process of EFH components 1 and 7 and EFH analyst responses are discussed in detail in Attachment 1: Report of Stock Assessment Author Review of EFH Components 1 and 7 for the 2022 EFH 5-year Review. Chapter 1 of the report introduces the EFH 5-year Review process, describes the 2017 EFH 5-year Review of EFH component 1, new component 1 information in development for the 2022 Review, and the review of EFH component 7. Chapter 2 provides an overview of the SA Review process for EFH components 1 and 7 that was co-developed by EFH analysts and SAs for the 2022 EFH 5-year Review. Chapter 3 reports the results of the SA review with a summary of the communications between SAs and EFH analysts receiving and responding to input, such as changes made to the component 1 information resulting from the SA review. Chapter 4 shares concluding remarks, Chapters 5 and 6 list contributors and literature referenced, and Appendices further summarize the SA review process and results.

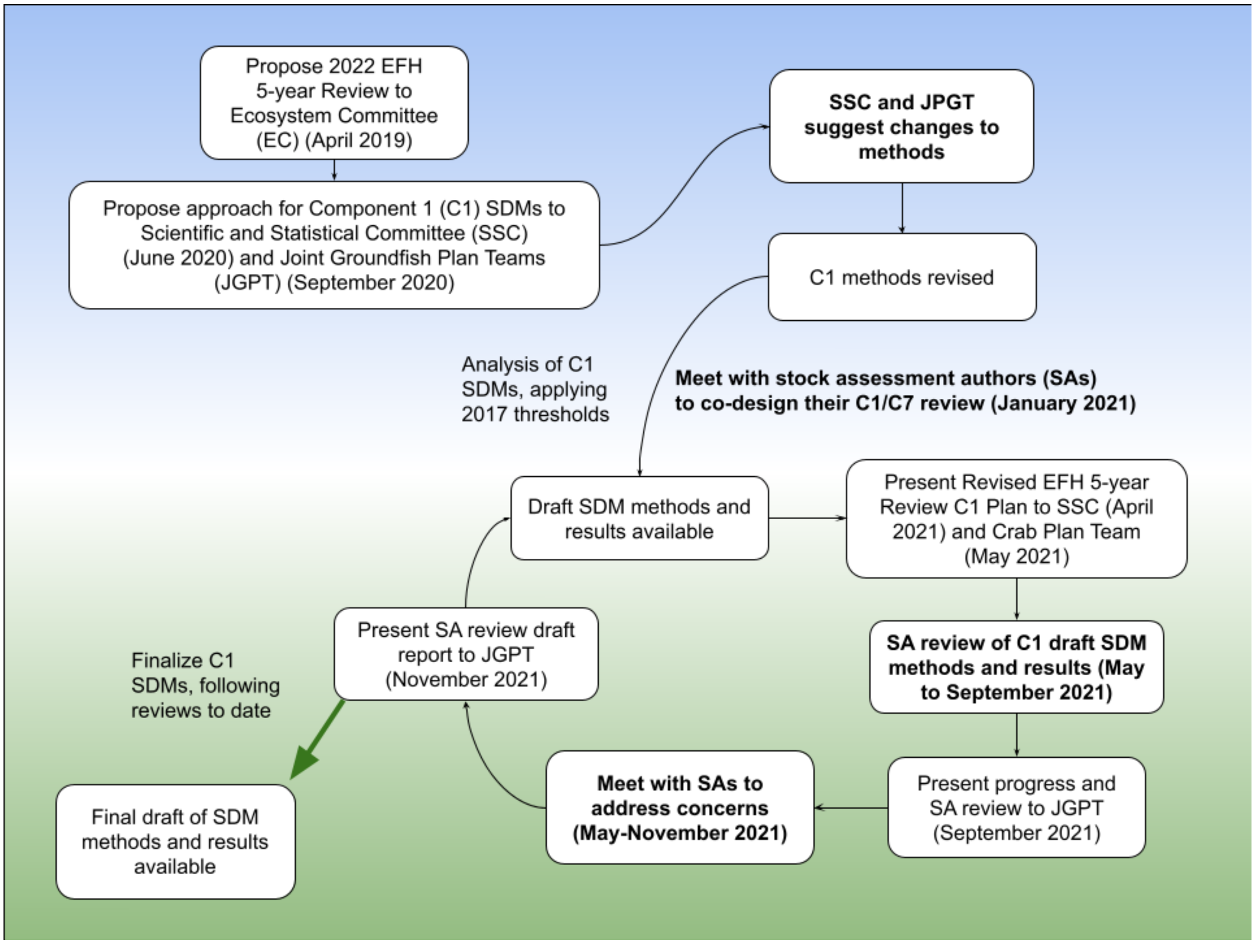

Figure 1. Iterative review process for EFH component 1 (C1) species distribution model (SDM) methods and results. Bold text indicates steps where the Scientific and Statistical Committee (SSC), Plan Teams, stock assessment authors, species experts, and other stakeholders provided reviews.

3 ADVANCING MODEL-BASED ESSENTIAL FISH HABITAT DESCRIPTIONS FOR NORTH PACIFIC SPECIES

The purpose of this study (hereafter referred to as **Laman et al. study**) is to describe and map EFH for federally managed North Pacific groundfish and crab species in the EBS, AI, and GOA using SDMs and to advance levels of EFH information for the life stages of those species. This study is guided by the Alaska EFH Research Plan (Sigler et al. 2017) research priority 1 to characterize habitat utilization and productivity using the best available scientific information to accomplish the two specific research objectives of the revised plan—

Objective 1 – Develop EFH Level 1 information (distribution) for life stages and areas where missing, and

Objective 2 – Raise EFH level from 1 or 2 (habitat related densities or abundance) to Level 3 (habitat related growth, reproduction, or survival rates).

To meet the research priority and objectives described above, we demonstrate a **revised SDM ensemble EFH approach** for the 2022 EFH 5-year Review, where EFH is described and mapped for 32 North Pacific groundfish species in the EBS, 25 in the AI, 42 in the GOA across up to three life stages. In addition, EFH is described and mapped for five crabs in the EBS, two crabs in the AI, and octopus in all three regions. All of the ensembles constructed for FMP species in the EBS, AI, and GOA in this present work describe and map EFH Level 2 (habitat related abundance). For early juvenile life stages in the GOA, SDMs describe and map EFH Level 1 for the first time. EFH Level 3 (habitat related vital rates) is described and mapped for a subset of species in each region for the first time.

The Final Environmental Impact Statement for EFH Identification and Conservation in Alaska defines EFH as the area inhabited by 95% of a species' population (NMFS 2005)[38]. Our habitat-based modeling approach characterizes EFH for species' life stages as **the spatial domain containing 95% of occupied habitat (where occupied habitat is defined as locations where predicted species encounter probability is greater than 5%).** As in the 2017 EFH 5-year Review, we provide maps of SDM predictions and EFH area percentiles, where subarea percentiles are the upper 75% ("principal EFH area"), upper 50% (core EFH area; the subarea used in the EFH component 2 fishing effects analysis of the 2017 EFH 5-year Review), and upper 25% ("EFH hot spots"). Presenting this set of maps demonstrates that the SDMs can identify more nuanced habitat-related spatial patterns of species distribution and abundance than is communicated by the EFH area (upper 95%) alone, which expands the utility of these SDMs and provides a basis for discussions on how EFH is mapped for the North Pacific region.

We have refined and advanced the science of using SDMs to describe and map EFH while measurably improving model performance compared to the SDMs developed for the 2017 EFH 5-year Review. The combination of refinements to modeling techniques, advances in life history studies, and addition of new data and data sources resulted in differences in the areal extent of EFH compared with 2017. We provide regional case studies for species' life stages that illustrate in a stepwise fashion how each modeling refinement or data addition applied by our present work affected EFH areal extent. We summarize and compare the results of this study and the 2017 SDMs and EFH maps in the Results section and Appendices of this Discussion Paper and in the Attachments, including 2017 and 2022 EFH area overlay maps (Attachment 2), and three regional Technical Memoranda with detailed results for each species' life stage modeled (Attachments 3-5).

[38] https://repository.library.noaa.gov/view/noaa/17391

3.1 What's New?

3.1.1 Overview of Data Updates and Model Refinements

Since the 2017 EFH 5-year Review, we have updated our SDM inputs (dependent and independent variables) and refined our modeling methods (Table 1). In this section of this document we provide highlights as an overview of what is different about the updated data and modeling approaches. The complete methods for our SDM ensemble approach to describe and map EFH is included below in the Methods section. The attached three regional Technical Memoranda (Attachments 3-5) provide region-specific methods details where applicable.

3.1.2 Response Variables

The dependent response variables used in our SDM are species occurrence (i.e., encounter/non-encounter) and numerical abundance. Fundamental differences between the response variables presented in the 2017 EFH 5-year Review SDM are that we now use the complementary log-log (cloglog) link to approximate abundance (Fithian et al. 2015) from presence-only and presence-absence models (formerly reported as probability of suitable habitat or probability of presence, respectively) and we use count data with a log-linked Poisson distribution and log-area swept (fishing effort) as an offset instead of 4th-root transformed catch-per-unit-effort (CPUE) and a Gaussian distribution. In the present models, we have incorporated an additional five years of NMFS Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl survey data (Table 2), extending the terminal year of the dataset from 2014 to 2019. We have also included new sources of data to assess the settled early juvenile life stages that extend our EFH mapping to this critical ontogenetic phase (Table 3).

3.1.3 Life History Information

Demography and length-based life stage definitions have been updated since the 2017 EFH 5-year Review (Table 4). Updated maturity schedules can be used to re-define subadult and adult life stage breaks for several species. Additionally, we include for the first time the ecologically important settled early juvenile life stage and describe their EFH for a subset of groundfish species in all regions. Inshore survey data from the recent update to the AFSC Nearshore Fish Atlas (NFA) of Alaska (Johnson et al. 2012, Grüss et al. 2021), Alaska Department of Fish and Game (ADFG) small-mesh bottom trawl survey (Jackson and Ruccio 2003, Spalinger 2020), and the AFSC Marine Ecology and Stock Assessment Program (MESA) juvenile sablefish tagging program (Echave et al. 2013), are combined with AFSC RACE-GAP large-mesh bottom trawl survey data to support modeling the settled early juvenile life stages of groundfishes in GOA (Table 3). Case studies of GOA Pacific cod present the SDM ensemble approach for adults and the SDM with combined survey data approach using presence-only MaxEnt models for the settled early juvenile life stages (GOA only) (see Results section).

3.1.4 Independent Variables

Several independent variables have been updated or added to the suite of habitat covariates for the SDMs (Table 5). The bathymetry compilation for the GOA has been extended west and updated (Zimmermann and Prescott 2015, Zimmermann et al 2019). Consequently, we revised the bathymetry-derived seafloor slope covariate for the GOA. We also added a measure of bathymetric position, and terrain curvature and aspect as new covariates for all regions. We developed a new metric of seafloor rockiness for the AI and GOA (e.g., Pirtle et al. 2015, 2019), and incorporated the most recent substrate data in the Bering Sea (Richwine et al. 2018). Five additional years of environmental data collection during the RACE-GAP summer bottom trawl surveys (2015-2019) and the addition of bottom temperature data from the coastal GOA regional ocean modeling system 3 km grid (Coyle et al. 2019)

(1999-2019; applied to models of settled early juveniles only) have resulted in updates to the regional bottom temperature dynamic covariates.

3.1.5 Modeling Refinements

In the 2017 5-year Review, SDM methods were assigned to a species and life stage *a priori* based on their prevalence in trawl survey catch (Laman et al. 2018). In the case studies presented here, we use a new approach that fits multiple SDMs and then assembles them into a weighted ensemble. The five SDMs (MaxEnt = maximum entropy model, GAM_P = Poisson generalized additive model, GAM_{nb} = negative-binomial GAM, paGAM = presence-absence GAM, and hGAM = hurdle GAM) are weighted by their inverse squared root mean-square error (RMSE). The final prediction is the weighted average of the SDM predictions, and the standard error for predictions is calculated from the standard error for each constituent model as well as variance among ensemble members (Table 1). SDMs may be removed from the ensemble if they fail to converge, produce implausible results (predictions are greater than 10 times highest observed abundance), or if the RMSE for that SDM is high relative to the others (measured as receiving less than 10% weight in the ensemble). Additionally, the GAM_P and GAM_{nb} are never included in the same ensemble because they are structurally very similar. Figure 8 shows a flowchart illustrating the different steps used to fit the SDMs and construct the ensemble. Analyses are conducted in R (R Core Development Team 2020) using the maxnet and mgcv packages (Phillips 2017, Wood 2011).

3.1.6 Introducing EFH Level 3

We describe and map EFH Level 3 (habitat related vital rates) for a set of groundfish species' settled early juvenile life stages for the 2022 EFH 5-year Review. This was done by integrating temperature-dependent vital rates developed from field and laboratory studies with habitat-related SDMs. Temperature-dependent vital rates have been published or are in development for groundfish species in the BSAI, GOA, and Arctic FMPs (Table 6). Laurel et al. (2016) described the temperature-dependent growth rate of early juvenile Pacific cod (and other gadids), which we use as a representative example to demonstrate our EFH Level 3 approach in this Discussion Paper.

3.1.7 Advancing EFH Information Levels

The many updates and additions to survey data described above, along with advances in demographic information and refinements to modeling techniques, help us to meet the EFH Research Plan objectives addressing EFH mandates for Alaska while achieving application of the best scientific information. The EFH Final Rule[39] requires that the periodic reviews of EFH take into account available information such as published scientific literature, unpublished scientific reports, and previously inaccessible or unavailable data sources, as we have done here. Modeling refinements to our SDM approach have improved our methodology and will advance EFH information levels for many FMP species in Alaska (Table 4, Appendix 3 Table A3.1). Integrating new data with the modeling refinements has improved the quality of our SDM EFH approach and helped us to meet the two specific research objectives in the revised EFH Research Plan for Alaska (Sigler et al. 2017), to develop Level 1 (distribution) or Level 2 (habitat-related densities or abundance) EFH information where missing, and raise EFH information to Level 3.

3.2 Methods

3.2.1 Study areas

In the present work, three marine regions of Alaska were the focus of species distribution modeling efforts focused on mapping and describing EFH for North Pacific groundfish and crabs species.

[39] 50 CFR 600.815

These regions extend from Dixon Entrance in southeast Alaska, through the Gulf of Alaska and along the Aleutian Islands archipelago to Stalemate Bank, and north across the eastern Bering Sea shelf and slope into the Northern Bering Sea.

3.2.1.1 Bering Sea

The Bering Sea study area includes the eastern Bering Sea (EBS) continental shelf (0 to 180 m), EBS upper continental slope (~200 m to 1000 m), and the northern Bering Sea (NBS) (Figure 2). Throughout this document, we refer to the shelf, slope, and NBS collectively as the EBS, which represents a total area of approximately 2,350,000 km^2. The EBS encompasses a diverse mosaic of benthic habitats. Much of the continental shelf, which extends more than 200 km from shore, is shallow, flat, and composed of soft unconsolidated sediments (Smith and McConnaughey 1999, Rooper et al. 2016). The shelf region is commonly divided into three domains: the inner shelf (0 to 50 m), middle shelf (50 to 100 m), and outer shelf (100 to 180 m; Coachman 1986). The shelf-slope break is located between 180 and 200 m depth, except at the northern edge of Bering Canyon, where the shelf-slope break is around 200 m (Sigler et al. 2015). The EBS upper continental slope (~200 m to 1000 m) is steep and includes five major canyon systems along its north-south axis. The seafloor of the upper continental slope is interspersed with areas of rocky substrata, especially in Pribilof Canyon, but is mainly dominated by soft unconsolidated sediments (Rooper et al. 2016). The northern Bering Sea is considered a distinct region and is not as well described as the more frequently sampled eastern Bering Sea shelf and slope. Grebmeier et al. (1988) indicated that the seafloor in the northern Bering Sea near Norton Sound is shallow, with average water depths < 50 m, and is composed of unconsolidated sediments similar to those found on the EBS continental shelf, although there is substantial variation in grain size that affects infaunal prey composition.

3.2.1.2 Aleutian Islands

The Aleutian Islands are a chain of volcanic islands stretching from southwest Alaska across the North Pacific, separating the western Gulf of Alaska (GOA) from the Bering Sea (Figure 3). The continental shelf and upper continental slope represent a diverse mosaic of benthic habitats from Unimak Pass (165°W) in the eastern Aleutian Islands to Stalemate Bank in the western Aleutians (170.5°E). The Alaska Coastal Stream flows westward on the Pacific side of the Aleutians, while on the Bering Sea side, the Aleutian North Slope Current flows eastward (Stabeno et al. 1999, Stabeno et al. 2002, Ladd et al. 2005). There is extensive transport to the north through passes in the island chain from the Pacific side to the Bering Sea. In the Aleutians, there is a very narrow continental shelf that ranges in width from 20 km to greater than 200 km. The continental slope is steep and features multiple passes incising the continental shelf. The seafloor of the Aleutian Islands is diverse, with extensive rocky substrate resulting from volcanic activity dominating the continental shelf (Zimmermann et al. 2013).

3.2.1.3 Gulf of Alaska

The GOA study area for these modeling studies extends from Dixon Entrance (131°W longitude) in southeastern Alaska to Unimak Pass (165°W° longitude) at the western edge of the Alaska Peninsula (Figure 4). The GOA coastline in this region forms an intricate complex of many bays and islands with diverse terrestrial and marine habitats (Johnson et al. 2012, Zimmermann 2019). The GOA continental shelf and upper continental slope encompass a mosaic of benthic habitats with extensive rocky substrate that has been uplifted due to tectonic activity and deposited by glacial retreat (Carlson et al. 1982, Zimmermann et al. 2019). Much of the continental shelf is dominated by soft unconsolidated sediments (Golden et al. 2016) and is narrow in southeastern Alaska and in the western GOA, but is relatively broad in the central GOA with numerous glacial troughs (Carlson et al. 1982, Goldstein et al. 2020) and islands throughout. The shelf break occurs at about 200 m throughout the GOA and the shelf itself is deeply incised by numerous gullies and troughs. Oceanic currents in the GOA ecosystem are the Alaska Coastal

Stream and Alaska Coastal Current which both flow westward (counter-clockwise) around the GOA from Dixon Entrance to the Aleutian Island chain (Stabeno et al. 2004). These currents result in downwelling of surface water at the coast while seasonal freshwater discharge results in a highly stratified system in the summer (Stabeno et al. 2004, 2016).

3.2.2 Species Data

3.2.2.1 Large-mesh Bottom Trawl Surveys

Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys document the distribution and abundance of federally managed fish and invertebrate species in the eastern Bering Sea (EBS), Aleutian Islands (AI), and the Gulf of Alaska (GOA). The EBS bottom trawl survey has been conducted annually since 1982 and the present studies for this region use RACE-GAP survey data through 2019. The Aleutian Islands data set combines the AI and GOA surveys west of the faunal barrier represented by Unimak Pass (Stabeno et al. 2002). The AI and GOA surveys have been conducted at regular intervals since 1991 and are collectively referred to in this document as the AI survey. In the AI, triennial surveys were conducted between 1991 and 2000 and biennial surveys were conducted from 2002 to 2018 (von Szalay and Raring 2020). The western portion of the GOA survey characterizes the eastern portion of the Aleutian chain south of the archipelago and was conducted triennially from 1993 to 1999 and then biennially from 2001 to 2019 (von Szalay and Raring 2018). Both of these fishery-independent AFSC RACE-GAP surveys used a stratified random sampling design. RACE-GAP summer bottom trawl surveys and the data years included in the SDMs for the 2017 EFH 5-year Review and in the present study for the 2022 EFH 5-year Review are provided in Table 2. We refer the reader to the attached Technical Memoranda for more detailed descriptions of the sampling strata for each region (Attachments 3-5).

We used species-specific, length-based life stage definitions of settled early juveniles, subadults, and adults supported in the literature, from web resources, or from the smallest, species-specific mean length from beach seines recorded in the AFSC Nearshore Fish Atlas (Table 4) to apportion trawl catches into life stages by computing the proportional contribution of each stage in the random subsample for fish lengths in that trawl to each species' total catch. Not all species catches could be apportioned into life stages so that proportional contribution to catch length composition could not be determined and SDMs were calculated for all individuals of that species using a single combined life stage.

3.2.2.2 Bering Sea Large-mesh Bottom Trawl Surveys

The primary source for fish and crab distribution and abundance data from the EBS is the 1982–2019 annual fishery-independent AFSC RACE-GAP summer bottom trawl survey of the EBS continental shelf. Additional data included in our analyses were obtained from the AFSC RACE-GAP EBS upper continental slope survey (Hoff 2016) occurring in years 2002, 2004, 2008, 2010, 2012, and 2016 and AFSC RACE-GAP NBS surveys (Lauth 2011) in 2010, 2017, and 2019. Scientific bottom trawl survey samples have been collected in the EBS since the 1940s, but the first systematic survey of the EBS shelf was conducted in 1975 by the U.S. Bureau of Land Management. In 1982, EBS shelf bottom trawl surveys were standardized and have since been conducted annually during the summer under a repeatable systematic sampling design (Lauth and Conner 2014). For this reason, we include trawl survey data from 1982–2019 in our analyses. During this time frame, changes in taxonomic classifications have resulted in different time series for analyses of different species (Attachment 3 Table 1).

Three standardized AFSC RACE-GAP summer bottom trawl surveys are conducted in U.S. waters of the Bering Sea. The Bering Sea continental shelf summer bottom trawl survey is conducted annually on a regular 25 nautical mile (nm) grid using an 83-112 Eastern trawl (112' footrope and 83" headrope). To better assess local blue king crab concentrations, "corner stations" are added to the regular

Bering Sea shelf survey grid in the water surrounding St. Matthew Island and the Pribilof Islands (Lauth et al. 2019). In recent years, the survey grid and sampling methodology have been extended to include the NBS and Norton Sound (Lauth 2011). The bottom trawl survey of the Bering Sea upper continental shelf and slope has been conducted quasi-biennially since 2002 at depths from 200 to 1200 m using a Poly Nor'Eastern high opening trawl net with bobbins and roller gear on the footrope and a stratified sampling design (Hoff and Britt 2011). We combined successful standard summer bottom trawl survey catches from the Bering Sea continental shelf and NBS (N = 14,514) with the successful Bering Sea upper continental slope trawls (N = 1,136) to estimate numeric abundance, length composition, and area swept (Alverson and Pereyra 1969) as inputs for the SDMs. Trawl catches included in modeling efforts had satisfactory trawl performance and the geographic location, distance fished, and water temperature at trawl depth were recorded for each trawl haul. Trawl hauls were satisfactory if the net was open within a predetermined "normal" range, the footrope maintained contact with the seafloor, and the net suffered little or no damage during towing. A total of 15,650 bottom trawl survey hauls from the EBS study area (1982–2019) met these criteria.

3.2.2.3 Gulf of Alaska and Aleutian Islands Large-mesh Bottom Trawl Survey

Assignment of sampling effort within strata for GOA and AI surveys was determined using a Neyman optimal allocation sampling strategy (Cochran 1977) which considers relative abundance and variance of commercially important groundfish species from previous surveys of the area as well as the previous year's ex-vessel price for select species. During the time period of these data collections, changes in taxonomic classifications have resulted in different effective time series for different species and these are reflected in the analyses presented here (Attachments 4 and 5; Table 1). For example, dusky and dark rockfishes were considered a single species prior to the 1996 survey so that only data since that survey were used to separately model these two species. All fishes and invertebrates captured by the trawl net were identified to species, or into higher level taxonomic groups, and weighed. Non-colonial taxa were also counted or estimates of total count were made. For species where length-based definitions of life stages were available, length ranges for settled early juveniles, subadults, and adults were used to partition the catch based on proportionality estimated from the random length subsample taken from each catch. These length-based definitions of ontogenetic life stages came from the extant scientific literature, web resources (e.g., the Ichthyoplankton Information System, AFSC RACE: https://access.afsc.noaa.gov/ichthyo/speciesdict.php), or length data collected in beach seines, purse seines, and small-mesh bottom-trawls and recorded in the updated Nearshore Fish Atlas (as described in Grüss et al. 2021) (Table 4).

The fishing gear used on the RACE-GAP AI and GOA bottom trawl surveys consists of a Poly Nor'Eastern high-opening bottom trawl with a 27.2 m headrope, a 36.3 m footrope, and 24.2 m roller gear constructed with 36 cm rubber bobbins separated by 10 cm rubber disks (Stauffer 2004). Under fishing conditions, the average net width is 16.0 m and average height is 6.7 m based on acoustic net mensuration equipment mounted on the wing-tips and headrope of the trawl. Each trawl was certified as conforming to measurements and dimension standards prior to its use in the survey as stipulated in the National Trawling Standards (Stauffer 2004).

3.2.2.4 Other Surveys

Three other surveys are included in the present study as additional data sources to parameterize SDMs for the groundfish settled early juvenile life stages in the GOA (Table 3). These surveys used a variety of gear types and were conducted inshore of the RACE-GAP summer bottom trawl surveys and in nearshore areas where the settled early juvenile life stages of groundfish also occur (Laurel et al. 2009, Pirtle et al. 2019, Grüss et al. 2021).

3.2.2.5 Gulf of Alaska Small-mesh Bottom trawl Survey

The Alaska Department of Fish and Game (ADFG) has conducted a series of fishery-independent small-mesh bottom trawl surveys (Jackson and Ruccio 2003, Spalinger 2020), which provided a new source of groundfish distribution and abundance data for the GOA. This summer survey targets shrimp, forage fishes, and commercially important groundfish species on the central and western GOA continental shelf, including areas inshore of the GOA RACE-GAP survey grid. The small-mesh survey uses a fixed-grid station design where stations are pre-selected randomly and deploys a high-opening box trawl constructed with 3.2 cm mesh throughout and designed to sweep a 9.8 m path at a height of 4 m which is the ADFG, NMFS, and Department of Fisheries and Oceans of Canada standard for shrimp trawl research. Since 1973, either ADFG or NMFS have conducted this small-mesh bottom trawl survey annually in the GOA (Jackson and Ruccio 2003, Spalinger 2020). In 2015, funding was reduced and a fishery-independent small-mesh survey was no longer possible. However, the survey was maintained at a minimal level in bays around Kodiak Island to provide a baseline to monitor the shrimp population from 2016 to 2019. Additional funding has recently been made available to continue the survey more broadly in 2020 and 2021.

In the present study, we used ADFG small-mesh bottom trawl survey data to parameterize SDMs of settled early juvenile life stages of groundfishes from survey years in the GOA spanning 1989–2019 (Table 3). Groundfishes collected on the survey were identified to species or genus level and fish lengths were measured to the nearest millimeter. This small-mesh survey catches all demersal life stages of our target groundfish species, providing the opportunity to use length data from the small-mesh survey to contribute to defining limits for length-based life stage definitions. In addition, these data hold the potential for future SDM EFH mapping that accounts for habitat use of other groundfish life history stages in areas inshore of the GOA RACE-GAP survey grid.

3.2.2.6 Nearshore Mixed Gear Surveys

AFSC Auke Bay Laboratories (ABL) has historically curated their nearshore fish surveys in a centralized, relational database called the Nearshore Fish Atlas (NFA; Johnson et al. 2012). The NFA database was developed in 2003 to consolidate the ABL's southeastern Alaska beach seine data dating back to 1998 when NOAA's EFH funds first became available. By 2012, the NFA database was made available online and contained 19 years of fish catch data from more than 1,300 beach seine hauls made in shallow, nearshore waters (within 20 m of shore and shallower than 5 m) of southeastern Alaska, the Aleutian Islands, Prince William Sound (PWS), Cook Inlet, Bristol Bay, and the Arctic region, making it the largest online repository of Alaska nearshore fish data (Johnson et al. 2012).

In 2019, the offline NFA database was updated for the primary purpose of modeling and mapping EFH (Grüss et al. 2021). Although the NFA started as a beach seine database, catch data from other gear types have been archived in the offline version for years. The 2019 expansion of the NFA with contemporary survey data from multiple gear types, including beach seines, purse seines, bottom and midwater trawls, gillnets, jigs, fyke nets, and minnow traps, quintupled the number of data entries (to 85,827), with the majority of these entries in the GOA. The online NFA database will be updated to this most recent version, soon (Lindeberg pers. comm.).

In the present studies, we used survey data from the updated NFA (1995-2019) to parameterize SDMs of settled early juvenile life stages of groundfishes in the GOA (Table 3). We restricted data extracts to survey gear types of beach seine (3.2 cm mesh), purse seine (3.2 cm mesh), bottom trawl (various mesh sizes), and jigs. This wide variety of gear types represent several sampling designs in a variety of habitats inshore of the GOA RACE-GAP survey grid. The NFA provides the opportunity to use length data collected by the inshore surveys to define lower limits for length-based life stage definitions of the settled early juvenile stage. The lower length limits of settled early juvenile stages from inshore surveys were compared to the maximum transformation lengths of the pelagic early juvenile stages that were sampled in the field prior to settlement (e.g., Doyle et al. 2019). Additional details about the NFA are available in Johnson et al. (2012) and recent updates to the NFA in Grüss et al. (2021).

3.2.2.7 Juvenile Sablefish Tagging Program

Beginning in 1985, juvenile sablefish have been sampled by jig, tagged, and released in a number of bays and inlets in southeast Alaska by the AFSC ABL Marine Ecology and Stock Assessment Program (MESA) (Echave et al. 2013). Annual sampling in St. John Baptist Bay near Sitka on Baranof Island is used as an indicator of the potential strength of an upcoming cohort. Tagging efforts have expanded to several areas of the central GOA, following reports of high catch rates in recent years (Goethel et al. 2020). The juvenile sablefish tagging program is included in the present study as an additional data source to parameterize SDMs for the sablefish settled early juvenile life stage, using capture locations throughout the GOA for years 1985–2020 (Table 3).

3.2.3 Habitat Covariates

The independent covariates used to parameterize SDMs (Table 5) for EBS species (Figure 5), AI (Figure 6), and GOA (Figure 7) were chosen on the basis of their potential to influence the distribution and abundance of North Pacific groundfish and crab life stages in the three regions. Some of these independent covariates (or predictor variables) were dynamic or static habitat attributes typically collected on the bottom trawl survey. Others were derived and modeled variables describing the marine environment in the study area (e.g., NEP5 ROMS; Danielson et al. 2011). They were combined into a suite of independent covariates used to parameterize the SDMs. We used variance inflation factors (VIF; Attachment 3-5; Table 3) calculated using the methods in Zuur et al. (2009) to eliminate strongly collinear terms (VIF ≥ 5.0; Sigler et al. 2015). Independent habitat covariates from each regional survey data time series (e.g., AI 1991–2018) were interpolated on regular spatial grids ranging from 0.1–1 km2 using natural neighbor interpolation (Sibson 1981), inverse distance weighting (Watson and Philip 1985), ordinary kriging (Venables and Ripley 2002) with an exponential semi-variogram, or empirical Bayesian kriging with a semi-variogram estimated using restricted maximum likelihood (REML; Diggle and Ribeiro 2002). Interpolation by inverse distance weighting and ordinary kriging were calculated on the R computing platform (R Core Development Team 2020) and Bayesian kriging was generated in ESRI ArcGIS mapping software. Rasters for our analyses were gridded at a resolution of 1 km^2. Rasters were gridded at a resolution of 100 m^2 for our analysis of the settled early juvenile life stages in the GOA only. All rasters were projected in the Alaska Albers Equal Area Conic (EAC) projection (standard parallels = 55° and 65°N and center longitude = 154°W).

For bottom temperature and bottom depth, year- and trawl-location-specific values were used for model fitting while long-term averages of those values were used to model abundance and to map EFH. All other habitat covariates were extracted from rasters of long-term average values at the bottom trawl stations by averaging the raster values along the towpath of each haul. Rasterized multi-year averages of all habitat covariates in each raster cell (including bottom depth and bottom temperature) were then used to represent average conditions in the study area over time, and were used in the ensemble models to predict species distributions and abundances and generate EFH maps. For species data sources supporting the GOA settled early juvenile stage models only, covariate raster values were extracted at point locations representing the geographic location of each sampling site. In both cases, these extracted predictors were used to train and identify the best fitting SDMs. When predicting species distribution and abundance, the complete raster of each retained covariate was used as input into the final models for a species and life stage. In the case of observed, dynamic predictor variables such as bottom temperature from the RACE-GAP survey, the observed values were kriged and rasterized over the study duration (e.g., AI 1991–2019) to represent average conditions in the study area over time (Table 2).

3.2.3.1 Bottom Depth and Temperature

We used two kinds of bathymetry data when formulating the SDMs used to model groundfish and crab distributions and abundances in the EBS, AI, and GOA. When fitting constituent SDMs, the bottom depth measured at each trawl station was used as a covariate predictor variable to train and test those SDMs. When predicting groundfish distribution and abundance for all life stages modeled, we used a bathymetry raster. For the EBS, this raster was built from several sources (Zimmermann and Prescott, 2018, Mark Zimmermann (AFSC) unpublished data, Steve Lewis (AKRO) unpublished data). For the AI, this raster was built from two sources that included data from the AI and the western GOA (Zimmermann et al. 2013, 2019). For the GOA, this raster was built from several sources (Zimmermann and Prescott 2014, 2015, Zimmermann et al. 2019, Coyle 2019). The primary sources for the bathymetry rasters were depth soundings from digitized NOAA National Ocean Service (NOS) smooth sheets from early hydrographic (Hawley 1931) and other surveys (hydrographic and non-hydrographic) that used manual soundings (e.g., lead lines), single-beam, or multi-beam acoustic echosounders. Details on the preparation and processing of the bathymetry datasets are documented in Zimmermann and Benson (2013) and Zimmermann et al. (2019). Point data from these compiled bathymetry datasets were gridded to the recommended resolution of 100 m^2, and also to create a raster surface using natural neighbor interpolation (Sibson 1981) in ArcMap. To achieve the 1 km^2 resolution used in our analyses, we averaged the 100 m^2 point data over 1 km^2 grid cells.

Similar to how we used depth data, we used temperatures measured at each trawl station to train and fit SDMs, then used a raster surface of those temperatures averaged across years to predict groundfish and crab distributions and abundances using the best-fitting SDMs in an ensemble. The bottom temperature raster was created by interpolating the observed temperatures at each trawl station over the entire study area and time series using empirical Bayesian kriging in ArcGIS (Diggle and Ribeiro 2002) with a semi-variogram estimated using restricted maximum likelihood (REML). The raster was interpolated over a 1-km^2 grid of the study area.

The GOA ROMS with integrated nutrient-phytoplankton-zooplankton (NPZ) is a high-resolution hydrodynamic model that is run using two domains, including a 3 km^2 resolution grid of the CGOA (coastal Gulf of Alaska) and an 11 km^2 grid of the Northeast Pacific with 42 vertical layers, as described in Coyle et al. (2019). The CGOA ROMS 3 km grid extends from Haida Gwaii in British Columbia to the Shumagin Islands and from the coastline to 1,200 km offshore. Bottom temperature values (°C) from May-September 1999–2019, were extracted from the deepest (closest to the seafloor) vertical layer at each point of the CGOA ROMS 3 km grid and averaged to produce a gridded 100 m^2 (natural neighbor interpolation) climatology surface of mean modeled bottom temperature (Attachment 5, Figure 3). This surface was used in the analysis of the settled early juvenile life stage SDMs and provided bottom temperature estimates for areas inshore of the GOA RACE-GAP survey grid.

3.2.3.2 Water Movement

Three attributes of water movement were used as habitat covariates in modeling and prediction: maximum tidal speed, bottom current speed and direction, and variability in bottom current. We estimated maximum tidal speed at each survey station over a lunar year (369 consecutive days between January 1, 2009 and January 4, 2010) using a tidal inversion program parameterized for each study region on a 1-km^2 grid (Egbert and Erofeeva 2002). This tidal prediction model was used to produce a series of tidal currents for spring and neap cycles at every bottom trawl survey station. The maximum of the lunar annual series of predicted tidal current was then extracted at each bottom trawl survey haul location. A 1-km^2 raster surface of maximum tidal current speed was kriged over the study region using an exponential semi-variogram and values were extracted and averaged along individual trawl haul towpaths to use as input to the best fitting SDMs when predicting distribution and abundance.

The second water movement variable was the predicted bottom water layer current speed and direction from ROMS models for that region (NEP5 for GOA and the AI, and Bering10K for the EBS) (Danielson et al. 2011; Kearney et al. 2020). These long-term current projections are available as points on a 10 km^2 grid. The ROMS model was based on a three-dimensional grid with 30 (EBS) and 60 (GOA/AI) depth tiers for each grid cell. The bottom current speed and direction for the deepest depth bin at each point (closest to the seafloor) was used in our analyses. These regularly spaced projections were interpolated to a 100 m^2 raster grid covering the study area using inverse distance weighting and then averaged over a 1 km^2 and across survey years (1991–2019) for our analyses. To characterize current at each bottom trawl station, ROMS current velocity components were extracted along each trawl towpath and the mean northing and easting values were computed for each trawl haul. The interpolated bottom current raster served as covariate input to the best fitting SDMs when making EFH maps.

Bottom current variability across summer months (May to September for GOA and AI, June to September for the EBS) was included as a third bottom current-related predictor in the SDMs. It was computed separately as the pooled standard deviation (Pooled SD_j) of the northing and easting components of bottom current at each NEP5 ROMS prediction locus through time such that:

$$Pooled\ SD_j = \sqrt{\frac{\sum_{i=1}^{k}\left[(n_i - 1) * s_{ij}^2\right]}{\sum_{i=1}^{k}[n_i - 1]}}$$

where j is the location of a prediction on the ROMS grid, n_i is the number of months projected in year i, s_{ij}^2 is the variance in bottom current speed at location j in across the months in year i, and k is the total number of survey years. The pooled standard deviation of bottom current speed represents the variability in currents from month to month while accounting for differences in the yearly mean. It can be considered a proxy for current stability near the bottom.

3.2.3.3 Geographic Location

Spatial modeling, such as the SDMs presented here, often include a location variable to represent geographic location and account for spatial autocorrelation (Ciannelli et al. 2008, Politou et al. 2008, Boldt et al. 2012). To reduce the effects of spatial autocorrelation on the results, we chose to combine latitude and longitude into a smoothed bivariate geographic location term included as an independent predictor in SDM formulations. Rooper et al. (2021) demonstrated that this approach can reduce spatial autocorrelation in the model residuals. Geographic location was collected during each haul using a variety of positioning systems through time (e.g., manual charting, long range navigation (LORAN-C), and digital global positioning system [dGPS]). Since 2005 (EBS) and 2006 (GOA and AI), start and end positions for the vessel during the on-bottom portion of the trawl haul were collected from a dGPS receiver mounted on the vessel. We corrected vessel position to represent the position of the bottom trawl by triangulating how far the trawl net was behind the vessel (based on the seafloor depth and the length of wire out) and subtracting this distance from the vessel position. We assumed that the bottom trawl was directly behind the vessel during the tow and that all bottom trawl hauls were conducted in a straight line from the beginning to the end point. The mid-point of the net’s trawl path between the start and end positions was used as the location variable in the SDMs. The EAC projected longitude and latitude data for each haul (and all other geographical data for this study) were projected to eastings and northings prior to modeling. A geographic location covariate was not used in the SDMs (MaxEnt) for the settled early juvenile life stages in the GOA).

3.2.3.4 Seafloor Terrain

Several seafloor terrain metrics were derived from the bathymetry surfaces and describe attributes of seafloor morphology. The attributes included in the present study were slope, aspect, curvature, and bathymetric position index (BPI). Seafloor terrain metrics were derived at the original scale of the compiled bathymetry surface (100 m^2) using neighborhood-based analytical methods in ArcGIS 10.7 (ESRI) with the Benthic Terrain Modeler (Wright et al. 2012, Walbridge et al. 2018). All seafloor terrain metrics were derived using a 3 x 3 neighborhood of grid cells, with the exception of BPI. Computation algorithms are provided by Walbridge et al. (2018).

Seafloor slope is the rate of change in bathymetry over a defined area. Slope is the first derivative of the bathymetry surface and was reported in degrees of incline (Dolan and Lucieer 2014, Horn 1981). Terrain slope may be a determinant of colonization since flatter areas support different substrata and communities than those found on steeper slopes (Pirtle et al. 2019).

Aspect measures the direction of the maximum gradient of slope and is expressed as angular compass direction, which is a circular variable (Horn 1981). Aspect was decomposed into sine (west-east or "eastness") and cosine (south-north or "northness") components to be used in the SDMs as continuous surfaces ranging from -1.0 to 1.0, where negative values indicate westness or southness and positive values indicate eastness or northness (e.g., Walbridge et al. 2018). Aspect eastness and northness were derived from the aspect surface. Terrain aspect is considered an indirect indicator of current velocity over and around seafloor terrain features (Mienis et al. 2007, Dolan et al. 2008).

Terrain curvature is the second derivative of the bathymetry surface and the first derivative of the slope (Schmidt et al. 2003, Zevenbergen and Thorne 1987). Curvature defines convex, concave, and linear slopes and can be used to identify seafloor features such as mounds and depressions that may be ecologically meaningful (Wilson et al. 2007). Curvature is also an indicator of how currents interact with the seafloor, either accelerating or decelerating parallel to the direction of slope and converging or diverging perpendicular to the direction of slope. We derived standard curvature as a single terrain surface, incorporating curvature in directions parallel and perpendicular to the slope (Zevenbergen and Thorne 1987, Schmidt et al. 2003). With this surface, positive values are convex slopes where currents may decelerate or diverge, negative values are concave slopes where currents may accelerate or converge, and values near zero are linear slopes where the rate and direction of flow is not expected to change.

Bathymetric position index (BPI) describes the elevation of one location relative to the mean of neighboring locations in an annulus-shaped neighborhood around a central cell or cells (Guisan et al. 1999, Weiss 2001). BPI emphasizes features shallower or deeper than the surrounding landscape area, such as ridges and valleys and places with abrupt changes in slope such as the continental shelf break and the base of the continental slope. Broad-scale measures of BPI (> 1 km) have been useful in distinguishing between areas of trawlable and untrawlable seafloor encountered by the RACE-GAP bottom-trawl survey (Pirtle et al. 2015). BPI has been used as an SDM covariate describing groundfish habitat in the GOA (Pirtle et al. 2019) and in other habitat analyses (Wilson et al. 2007, Howell et al. 2011). We derived BPI from EBS bathymetry rasters using a 64-cell radius neighborhood and from AI and GOA bathymetry rasters using a 65-cell radius neighborhood, both with an inner radius of 3-cells. This is equivalent to a horizontal scale of 6.4 km (6.5 km for GOA and AI), representing relatively broad-scale terrain features in our study area. In the resulting surface, positive values are shallower than the surrounding area (e.g., ridges and crests) and negative values are deeper (e.g., channels and valleys). In the visualization of this covariate, we artificially stretched the scale to highlight the heterogeneity that exists in the study area.

3.2.3.5 Seafloor Rockiness

A seafloor rockiness surface was developed for the AI and GOA based on a compilation of rock features and sediment attributes to represent a continuous gradient from areas with high occurrence of rocky substrate to areas with low occurrence of rocky substrate, using methods similar to Pirtle et al. (2019). The following datasets were included for the AI region: 1) sediment and substrate features from digitized smooth sheets (Zimmermann et al. 2013); 2) EBSSED-2 regional selection of samples collected from grabs and cores (Richwine et al. 2018); 3) modeled untrawlable and trawlable seafloor based on a generalized linear model of multibeam acoustic backscatter and terrain available as a 6 m^2 raster dataset (Pirtle et al. 2015) that was regridded to 1 km^2 (and 100m^2 for the GOA) and exported as point locations, where model predictions of untrawlable and trawlable locations are proxies for high and low occurrence of rocky substrate; and 4) RACE-GAP bottom-trawl survey historic haul locations, including hauls that incurred gear damage from seafloor contact to represent locations where untrawlable rocky features were likely encountered and hauls with good performance to represent locations where untrawlable rocky seafloor was likely not encountered, using the corrected start positions of the on-bottom portion of tows. Compiled point location data from the four datasets were gridded using natural neighbor interpolation to produce a raster surface of 1 km^2 resolution (ArcGIS 10.7, ESRI).

The following additional datasets were also applied for the GOA region: 1) sediment and substrate features from digitized smooth sheets (Zimmermann and Prescott 2014, 2015); 2) dbSEABED format sediment and substrate features (Golden et al. 2016); and 3) RACE-GAP bottom-trawl survey grid, using centroid locations for grid cells with codes indicating presence of rocky substrate features (rocky, pinnacles, snags, ledges, bottom too hard) and non-rocky substrate features (sand waves). Compiled point location data from the six datasets were gridded using natural neighbor interpolation to produce raster surfaces of 100 m^2 and 1 km^2 resolution (ArcGIS 10.7, ESRI).

For all of the seafloor terrain and substrate variables, values were extracted from their raster surfaces along the towpath at each trawl station and were used when training the models and identifying the best-fit SDM. The complete terrain raster was used to predict species distributions and abundances when a terrain covariate was retained in the best-fitting model.

3.2.3.6 Biogenic Structure

Previous studies have indicated that structure forming invertebrates (SFI) such as sponges, corals, and pennatulaceans (sea pens and sea whips) can form important structural habitat for temperate marine fishes (e.g., Rooper et al. 2010, Stone et al. 2011, Laman et al. 2015). The occurrence of SFIs can also be indicative of substratum type (Du Preez and Tunnicliffe 2011) because these sponges and corals attach to rocks and hard substrata, whereas sea pens and sea whips anchor into soft substrata. Therefore, we included the presence and absence of a) sponges, b) corals, and c) pennatulaceans as three binomial factors in the suite of habitat covariates. Presence-absence of these SFIs in trawl catches was used to train and identify the best-fitting SDMs. Rasters of modeled presence-absence for these SFIs (Rooper et al. 2014, 2016, 2017, Sigler et al. 2015) were used as covariate inputs into the final ensembles for predicting groundfish distribution and abundance.

3.2.4 Statistical modeling

Our modeling strategy for this 5-year EFH Review has been to fit multiple habitat-based SDMs to fish and crab abundances, skill test among SDMs using the root-mean-square-error to indicate model performance (RMSE; Hastie et al. 2009), and incorporate the best performing models into an ensemble in R (R Core Team 2020). Ensemble models essentially average predictions across constituent models, making them more robust to overfitting and less sensitive to differences in predictive performance among constituents. Rooper et al. (2017) found that ensembles performed better than the generalized linear or generalized additive models alone when predicting distributions of structure-forming invertebrates. Overall, the ensemble modeling approach provides a universal SDM application across multiple FMPs and can be easily expanded to consider additional constituent models in the future.

Previous EFH descriptions in Alaska (e.g., Turner et al. 2017), were based on habitat-related SDMs modeling species abundances from 4th-root transformed catch-per-unit-effort (CPUE; $kg \cdot ha^{-1}$) using the area swept method (Wakabayashi et al. 1985) and assuming a Gaussian distribution. Modeling 4th-root transformed CPUE has several shortcomings with respect to our study objectives, including: (1)

residuals were not informative due to the zero-inflation and overdispersion that cannot be properly addressed by a Gaussian distribution; (2) the a priori and ad hoc nature of deciding to use a 4^{th}-root transformation relative to other equally defensible transformations; (3) the inability to interpret the scale of the output, which is in units of 4^{th}-root CPUE and hence must be back-transformed to calculate a total predicted CPUE in any subarea; and (4) the scale-dependence of results, where the 4^{th}-root transformation implies that density would change if the area swept in the survey changed (i.e., if sampling had occurred at a different scale). To improve on the challenges associated with using the 4^{th}-root transformed CPUE, we directly modeled numerical abundance with an area-swept offset to generate EFH descriptions that were fitted directly to raw data without prior transformation; this more precisely represents fishing effort.

We modeled numerical abundance using five different SDMs (Table 4): a maximum entropy model (MaxEnt), a presence-absence GAM (paGAM), a hurdle GAM (hGAM), and two forms of standard GAM using the Poisson distribution (GAM_P) and the negative binomial distribution (GAM_{nb}). The MaxEnt and paGAM use presence or presence-absence data to estimate probabilities of occurrence (Phillips et al. 2006, Wood 2017). Using these models in conjunction with the complementary log-log (cloglog) link function allowed us to approximate abundance from the estimated probabilities (Scharf et al. 2019). Transforming these native model outputs (probability) into approximate numerical abundance yields predictions in the same units as the response variables from the other 3 SDMs which enabled skill testing and model comparison while meeting the requirements to qualify predictions as EFH Level 2, habitat-related density or abundance. Because some models, (notably MaxEnt) produce results on different scales, predictions were rescaled by dividing by the mean of predictions at tow locations and multiplying by the mean of observations. This ensured that predictions from all models were directly comparable and could be used to construct a weighted ensemble (Figure 8).

3.2.4.1 Maximum Entropy Models (MaxEnt)

Maximum entropy modeling was developed to model probability of suitable habitat or species occurrence with presence-only data (Phillips et al. 2006) in cases of rare species and when presence-only or presence-absence data were available from multiple surveys with varied sampling designs (Elith et al. 2011; Guisan et al. 2007). This newer version of the MaxEnt model, implemented with the *maxnet* package in R (Phillips et al. 2017; R Core Development Team 2020), reformulates the model as an inhomogeneous Poisson process, which constructs the predicted probabilities as a proportion of the product of underlying relative abundance and sampling probabilities. Because of this, it was possible to estimate the species abundance by treating the cloglog link output of the MaxEnt model as if it were the linear predictor in a Poisson model. The relative abundance estimate was then calculated by adding an additional parameter, the entropy, to the cloglog linear predictor and exponentiating the sum.

The MaxEnt model utilized the same suite of covariates as the GAMs, but omitted geographic location (lat/lon) from the suite of predictor variables because MaxEnt does not separately distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011). The MaxEnt algorithm automatically constructed and selected terms based on several feature classes determining relationships between the species response data and covariates. The default feature set was used in this study, which includes linear, quadratic, and product interaction terms. By default, hinge features were included in models with more than 80 presence records and threshold features were not used. As part of the fitting process, a variety of these different features were tested in different combinations. MaxEnt uses a regularization multiplier to determine the penalty applied to larger models and to help regulate overall model complexity. Here, we evaluated regularization multiplier values between 0.5 and 3.0 in intervals of 0.5 with the best value determined by the lowest RMSE after 10-fold cross-validation as described below (see Cross-Validation and Skill Testing 3.2.5).

3.2.4.2 MaxEnt for Settled Early Juvenile Life Stages in the GOA

We modeled the early juvenile life stage for several species in the GOA (first column in Table 4). Modeling the settled early juvenile life stage presented different challenges than those encountered when modeling later life stages. These smaller animals are not as readily retained in the standard RACE-GAP large mesh bottom trawl survey as larger animals, and they typically reside in inshore areas not sampled by the GOA RACE-GAP survey. To address these data gaps and so that we could model distribution of this critical life stage, we incorporated fishery-independent surveys with a variety of sampling designs and gear types into our analyses, including the GOA RACE-GAP survey and surveys from areas inshore of the GOA RACE-GAP survey grid (e.g., Pirtle et al. 2019). These additional sources consisted of the ADFG small-mesh bottom trawl survey (Jackson and Ruccio 2003, Spalinger 2020), data from multiple surveys stored in an update to the NFA database (2019) (e.g., Grüss et al. 2021), and the AFSC MESA juvenile sablefish tagging program (Echave et al. 2013) (Table 3). However, integrating data from multiple disparate surveys makes it difficult to separate catchability and fishing gear effects from actual differences in population abundance. To address these concerns we modeled settled early juvenile life stages from presence-only data rather than use the ensemble approach used for subadults and adults modeled solely from the RACE-GAP summer bottom trawl surveys.

As a method for combining multiple surveys with different designs and gear types (i.e., various bottom trawls, beach and purse seines, and jigs), we reduced all settled early juvenile stage observations to presence-absence only for inclusion in the MaxEnt model. MaxEnt treats data within a presence-only framework (Phillips et al. 2006), which has been useful to combine data obtained from multiple sampling designs and for data-limited species (Guisan et al. 2007, Elith et al. 2011). MaxEnt models have been previously applied to the settled early juvenile life stages of groundfish species in the GOA (Pirtle et al. 2019, Shotwell et al. *in pres*) and to juvenile and adult groundfish life stages in the GOA, EBS, and AI for the 2017 EFH 5-year Review (GOA-Rooney et al. 2018, EBS-Laman et al. 2017, AI-Turner et al. 2017). Here, we modeled the probability of suitable habitat with the *maxnet* package, which incorporates a newer MaxEnt algorithm and the cloglog link (Phillips et al. 2017). The GOA settled early juvenile MaxEnt models utilized the suite of covariates developed as 100 m^2 raster grids and omitted geographic location (lat/lon) since MaxEnt cannot distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011) (Table 5). For GOA settled early juvenile EFH, we produce Level 1 (habitat-related distribution) maps as a first approximation of the distribution of these groundfish early life stages based on the predicted probability of suitable habitat. This approach advanced the level of settled early juvenile life stage EFH information from none to EFH Level 1 for 11 groundfish species in this EFH 5-year Review (Objective 1; Sigler et al. 2017).

MaxEnt automatically constructs and selects terms based on several feature classes that determine relationships between the species response data and covariates. The default feature set was used in this study, which includes linear, quadratic, and product interaction terms. By default, hinge features are included in models with more than 80 presence records and threshold features are not used. As part of the fitting process, a variety of these different features were tested in different combinations. MaxEnt uses a regularization multiplier to determine the penalty applied to larger models and to help regulate overall model complexity. For settled early juvenile stage MaxEnt models, we evaluated regularization multiplier values between 0.5 and 3.0 in intervals of 0.5. All evaluations were carried out using the 10-fold cross-validation methods described below (see Cross-Validation and Skill Testing 3.2.5), with the exception that instead of using RMSE, we used AIC_c (Akaike 1974) to identify the best fit model:

$$AICc = \sum_{k=1}^{10} 2q_k - 2\ ln\ \widehat{L_k} + \frac{q_k^2 + 2q_k}{n_k - q_k - 1}$$

where q_k is the number of non-zero coefficients in the model for cross-validation fold k, n_k is the number of data points where the species is present for cross validation fold k, and $\widehat{L_k}$ is the likelihood for the model in fold k. Since MaxEnt does not utilize a standard error distribution and thus does not provide a likelihood, the *aic.maxent* function from the *ENMeval* package (Muscarella et al. 2014) was used to provide an approximation of AIC_c.

To assess model fit for settled early juvenile MaxEnt models, we calculated the area under the receiver operating characteristic curve (AUC) as a measure of overall prediction skill. The AUC measures the ability of model predictions to accurately discriminate between two options, such as a species being present or pseudoabsences that are generated during model fitting. An AUC of near 0.50 indicates poor performance, whereas a score of 1.0 indicates perfect discrimination (Hosmer and Lemeshow 2005). We also presented the spatial variation in model predictions as the standard deviation among the 10 replicates. Because the MaxEnt predictions were in units of probability bounded between zero and one, the standard deviation is easily interpretable without any further modification (Pirtle et al. 2019).

3.2.4.3 MaxEnt for All Life Stages in the EBS and AI and Subadult and Adult Life Stages in the GOA

MaxEnt models of the subadult and adult life stages only use distribution and abundance data from the RACE-GAP summer bottom trawl surveys. The MaxEnt model implemented with *maxnet* (Phillips et al. 2017; R Core Team 2020), reformulates the model as an inhomogeneous Poisson process, which constructs the predicted probabilities as a proportion of the product of underlying relative abundance and sampling probabilities. Because of this, it was possible to estimate species abundance by treating the cloglog link output of the MaxEnt model as if it were the linear predictor in a Poisson model. The relative abundance estimate was then calculated by adding an additional parameter, the entropy, to the cloglog linear predictor and exponentiating the sum. In this case, we comprehensively produced Level 2 (habitat-related abundance) maps and advanced the level of EFH information available for several species in this EFH 5-year Review.

This set of MaxEnt models utilized the same suite of covariates as the GAMs described below, but omitted geographic location (lat/lon) from the suite of predictor variables since MaxEnt cannot distinguish spatial variation in sampling probability from spatial variation in resource density (Elith et al. 2011). The MaxEnt algorithm automatically selected various feature classes and we tested a range (0.5-3.0) of regularization multipliers with the best value determined by the lowest RMSE after 10-fold cross-validation as described below in the subsection *Cross-Validation and Skill Testing*.

3.2.4.4 Generalized Additive Models (GAM)

We used three classes of GAMs in this study: the paGAM (Wood 2017), the hGAM (Cragg 1971, Barry and Welsh 2002, Potts and Elith 2006), and the standard GAM with a Poisson distribution (GAM_P; Hastie and Tibshirani 1990); and a negative-binomial GAM (GAM_{nb}; Zuur et al. 2009). All GAMs were fit using the *mgcv* package (Wood 2011) in R. The paGAM uses the binomial distribution and the cloglog link function, which made it possible to approximate numerical abundance from model predicted encounter probabilities (Fithian et al. 2015). The hGAM models presence-absence and abundance in two stages and accounts for zero-inflation commonly seen in field collected data (McCullagh and Nelder 1989). In the first stage of the hGAM, the probability of occurrence was predicted from presence-absence data using a paGAM and binomial distribution. In the second stage of the hGAM, a standard GAM was constructed for the positive catches using a “zero-adjusted” (Zuur et al. 2009) Poisson distribution. Finally, an abundance estimate was obtained by multiplying the predicted probability of presence from step one with the abundance estimate from step two (Manel et al. 2001, Barry and Welsh 2002, Wilson et al. 2005). The GAM_P estimates abundance directly using the Poisson distribution and a log link. The GAM_{nb} was structurally similar to the GAM_P but used a negative binomial distribution with a log link, allowing the GAM_{nb} to account for overdispersion in the data (McCullagh and Nelder 1989).

For all GAMs, we used iterative backward stepwise term elimination to remove covariate terms based on minimizing the model-dependent generalized cross-validation (GCV) or unbiased risk estimator (UBRE) scores thereby identifying the best fitting model formulations (Weinberg and Kotwicki 2008, Zuur et al. 2009). Since the Poisson and negative-binomial GAMs were structurally very similar models, we used RMSE-based skill testing to identify and keep the best performing model (lowest RMSE) of this pair in the ensemble.

All GAMs in this study used a variety of two dimensional smoothing terms, one dimensional smoothing terms, and categorical variables fitted to the abundance data. To avoid overfitting in the GAMs, the basis degrees of freedom used in the smoothing function for each habitat covariate were constrained following the methods of Weinberg and Kotwicki (2008). However, attempting to extrapolate model predictions into areas with few data points requires additional consideration. In particular, the default smoother when fitting GAMs, a "thin-plate spline," sometimes produces exaggerated predictions in areas of sparse data (Wood 2003). To counter this behavior in one dimensional smooth terms, we used a smoothing penalty based on the first derivative (as opposed to the default second derivative), which tended to push the effect curve towards zero where data were unavailable. For two dimensional smooth terms, the same method was applied, but "Duchon" splines were used instead of thin-plate or cubic splines (Duchon 1977) which did a better job of penalizing the smooth function in areas with sparse data. Finally, if a GAM based on thin-plate splines failed, a second version using cubic splines in the one dimensional smooth terms was attempted. If both versions failed to converge or produced unreasonable results, that particular GAM was excluded from the final ensemble.

3.2.5 Cross-Validation and Skill Testing

Species distribution models were subjected to k-fold cross-validation to estimate RMSE and to assess accuracy and uncertainty. We computed the error at each cross-validation fold (*k*) by fitting an SDM to a randomly selected "in-bag" partition containing 90% of the observed abundance at trawl stations (i), predicting abundance at the remaining "out-of-bag" partition containing the other 10% of trawl stations, and comparing the predicted (*y*) and observed (*x*) values for the testing subset. The k-fold cross-validation was repeated 10 times until every point in the data set had been tested and the RMSE from the accumulated out-of-bag sample was calculated as:

$$RMSE = \sqrt{\frac{\sum_{k=1}^{10}\sum_{i=1}^{n_k}(y_{ki}-x_{ki})^2}{\sum_{k=1}^{10} n_k}}$$

where y_{ki} is the predicted numerical abundance in cross-validation fold k, x_{ki} is the observed numerical abundance at trawl station i in cross-validation fold k, and n_k is the number of stations sampled in the kth fold. This process provides a test of prediction skill at unsampled locations within the cross-validation, and provides a measure of performance that can be used to compare models. The RMSE provides a metric of the ability of a model to accurately predict the abundance at a series of locations. The model with the lowest RMSE value was considered the best performer (Hastie et al. 2009). The cross-validation also allows for a consistent method of calculating the variance in model predictions by computing it at each location across folds.

Skill testing was used to eliminate constituent SDMs from the ensemble by identifying and dropping low-performing models with high RMSEs. Constituent SDMs retained in the ensemble were weighted by the inverse squared RMSE following the formula,

$$w_i = \frac{RMSE_i^{-2}}{\sum_{i=1}^{m} RMSE_i^{-2}}$$

where w_i is the weight for model *i*, $RMSE_i$ is the cross-validated RMSE for model *i*, and *m* is the number of constituent models. The inverse of RMSE-squared is sometimes called "precision", and precision-weighting (as we use here) is often the optimal weighting method e.g., as used in shrinkage estimators and hierarchical models. The inclusion of poor performing models may degrade ensemble performance so if any constituent SDM received less than a 10% relative weight, it was eliminated from the ensemble and the weights of the remaining SDMs in the ensemble were recalculated.

The ensemble model extrapolated abundance into areas along the edges of the survey grid that were rarely sampled as well as across regions in the Bering Sea like the EBS Slope and NBS which have been sampled at much lower frequency than the EBS shelf. Under these conditions, SDMs that fit the majority of the data quite well can still produce unacceptable predictions around the edges and in these unfrequented regions. The unacceptable predictions usually take the form of unrealistically high abundance. To address this challenge, a criterion was implemented so that any SDM generating abundance predictions > 10 times the highest observed survey abundance was excluded from the ensemble. The resulting cumulative ensemble-predicted numerical abundance, based on the combined effects of all retained constituent SDMs, was translated into a map of the complete EFH area for each species.

3.2.6 Ensemble Models and Uncertainty

Ensemble modeling is a robust method to predict species distributions and abundances (Aruajo and New 2007). Potential advantages include better estimates of uncertainty, reduced bias, and results that are less sensitive to minor changes in the underlying data (e.g., accumulating data through annual surveys; Stewart and Hicks 2018). In the present study, we combined the best-fit constituent SDMs into single species life stage-specific ensemble predictions of habitat-related abundance to inform descriptions of EFH. In practice, this means we first identified the best performing MaxEnt, paGAM, hGAM, and GAM SDMs. In the MaxEnt models, this entailed testing a range of regularization multipliers, while in the GAMs this involved backwards stepwise term elimination. For the standard GAM, the Poisson and negative binomial error distributions were modeled separately and skill testing using the RMSE was employed to select the distribution that best characterized the data. The set of best SDMs from each category was then precision-weighted (i.e., weighted by the inverse of its cross-validated RMSE) and constituent SDM weights were normalized to sum to one. Predictions from the ensemble were made by multiplying each constituent prediction by its weight and summing the weighted predictions across SDMs. The result of this exercise was a final ensemble for each species' subadult and adult life stage that predicts habitat-related abundance.

The variance of the ensemble prediction was obtained based on a weighted combination of the variance in the predictions of each constituent model. For each constituent, 10 abundance prediction rasters were made using the 10 models fit during cross-validation. The variance across these 10 folds at each location was then calculated to provide a variance estimate for that constituent model. After repeating this process for all constituent models in the ensemble, we adapted the following equation from Burnham and Anderson (2002), substituting our RMSE derived weights for their AIC weights:

$$SD_j(ensemble) = \sum_{i=1}^{m} w_i \times \sqrt{var_{ij} + \left(y_j^* - y_{ij}\right)^2}$$

where SD_j is the standard deviation of the ensemble at location j, w_i is the weight for model i, m is the number of constituent models, var_{ij} is the variance for model i at location j, is the ensemble abundance prediction at location j, and y_{ij} is the abundance prediction for model i at location j. Then we computed the coefficient of variation (CV) from the SD (ensemble) as:

$$CV_j = \frac{SD_j}{y_j^* + c}$$

where CV_j is the coefficient of variation at location *j*, SD_j is the ensemble standard deviation at location *j*, and y^*_j is the ensemble prediction at location j. Because the term y^*_j in the denominator can sometimes be close to zero, a small constant *c*, which was set at 1% of the max predicted abundance for that species and life stage, must be added to all abundance estimates when calculating the CV.

3.2.7 Species Distribution Model Performance Metrics

In addition to the RMSE described above for skill testing among SDMs and constituent model weighting in the ensemble, we computed three commonly used metrics of SDM performance for constituent models and the ensembles. The three metrics we reported were the Spearman's rank correlation coefficient (ρ), the area under the receiver-operator-characteristics curve (AUC; Hosmer and Lemeshow 2005), and the deviance explained based on the Poisson distribution (PDE). Each metric measures a different aspect of model performance and has distinct strengths and weaknesses. All models should be assessed with reference to the underlying biology of the species being studied.

The ρ score compares predicted densities with observations for each sample, computing their rank correlation, and measuring how well a model accurately distinguished between high and low density areas (Best and Roberts 1975, Zar 1984). We employ the ρ instead of the more familiar Pearson correlation because the ρ is more appropriate for count data that do not follow a normal distribution (Legendre and Legendre 2012). Additionally, the EFH maps produced in this project are based on ranked percentiles of area occupancy, and ρ may provide some insight into the accuracy of the EFH maps. While there is no objective standard for what constitutes a "good enough" correlation, for this project, we adopt the framework that less than 0.2 represents "poor" predictive performance, between 0.2 and 0.4 is "fair", between 0.4 and 0.6 is "good," and greater than 0.6 is "excellent." Our framework is based on our knowledge of the ecology of the species being modeled and the available data. Because ρ is the rank correlation, a high value is easiest to obtain when there is a large difference between the lowest and highest abundances, such that small prediction errors do not affect the rankings. Conversely, a low value can result if the observed densities occupy a narrow range and a small prediction error will change the rankings.

The AUC is a measure of the ability of a model to discriminate between binary outcomes, such as presence and absence. The value of the curve at any point represents the ratio of true positives to false positives at that point, and the total area under the curve is a representation of the overall performance across the entire range of values. The AUC has a minimum value of 0.5 (i.e., random 50/50 chance) and a maximum of 1, and values under 0.7 are generally considered poor, values between 0.7 and 0.9 are good, and values greater than 0.9 suggest excellent discrimination ability (Hosmer and Lemeshow 2005). The AUC provides a measure of discrimination ability that is standardized across the range of probability predictions, which makes it useful as a summary of discrimination ability. In this case, discriminating where the RACE-GAP bottom trawl survey catches individuals and where it does not. However, it can sometimes be misleading in situations where an overwhelming majority of observations are either present or absent and only a small portion of the probability space has been adequately sampled.

The PDE provides a generalization of "variance explained" for the constituent SDMs as well as the ensemble. We assume the Poisson distribution when computing the deviance explained for these models because count data are not normally distributed and traditional estimates of the variance explained tend to be misleading. Additionally, with the Poisson distribution, the size of errors is expected to change with the mean of the predictions. Therefore, it is common to compute the deviance explained by a model. This value is a measure of the percent reduction in the residual deviance of a model compared to a naïve null model, which contains only an intercept and no predictor terms. Because we employ a variety of models that utilize different distributions (binomial, Poisson, negative binomial), and different underlying data types (presence-absence, count), we estimate the deviance explained in comparison to a fixed null Poisson model. Therefore, the PDE represents the percent deviance explained in relation to a null Poisson model, which allows for a fairer comparison of the different models. We specifically extracted predicted numerical density as common currency from all models, and compared this prediction with the observed count at each station using the formula for deviance-explained for a Poisson distribution. In this case, we adopt a similar metric to the correlation, where less than 0.2 indicates "poor" performance, between 0.2 and 0.4 "fair" performance, between 0.4 and 0.6 "good" performance, and greater than 0.6 is "excellent" performance. A high PDE can result when model predictions are accurate, or when the observed data are highly variable and the model represents a significant improvement over a simple null model. Similarly, a low value can sometimes occur even when predictions are accurate if there is no improvement over the null model, indicating that a simpler method would probably be acceptable. Deviance is calculated as,

$$D = 2\sum_{i=1}^{n}\left[x_i ln\left(\frac{x_i}{exp(y_i)}\right) - \left(x_i - exp(y_i)\right)\right],$$

$$D_0 = 2\sum_{i=1}^{n}\left[x_i ln\left(\frac{x_i}{exp(\bar{x})}\right) - \left(x_i - exp(\bar{x})\right)\right], \text{ and}$$

$$PDE = \frac{D}{D_0},$$

where D represents the deviance of a given model, D_0 is the deviance of the null model, x_i represents the observed abundance for data point i, represents the mean of observed abundance, and y_i represents the predicted numerical abundance for data point i as calculated from the log- or cloglog-linked linear predictor used in each constituent model.

Species Distribution Model Performance Metric Rubric:

ρ: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent)

AUC: < 0.70 (poor), 0.71–0.90 (good), 0.90–0.99 (excellent)

PDE: < 0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (good), 0.61–0.99 (excellent)

3.2.8 Essential Fish Habitat (EFH) Maps

3.2.8.1 Encounter Probability

Encounter rates were derived from model predictions and used to remove locations that had low encounter probabilities from inclusion in the EFH area. For settled early juvenile MaxEnt SDMs in the GOA, the cloglog probability of suitable habitat was used in place of encounter probability. In settled early juvenile ensembles in other regions, as well as all ensembles for subadult and adult life stages, we assumed that the abundance predictions approximately followed a Poisson distribution. Under this assumption, the probability of encounter was equal to one minus the likelihood of zero abundance, given the predicted abundance at that location.

3.2.8.2 Mapping EFH from SDMs

New Level 1 EFH maps, based on habitat-related species distribution for the settled early juvenile life stage in the GOA, met an Alaska EFH Research Plan objective for this EFH 5-year Review (i.e., Objective 1: Develop EFH Level 1 information (distribution) for life stages and areas where missing; Sigler et al. 2017). For all settled early juveniles in other regions, subadults, and adults, maps of species' habitat-related abundance predicted from the ensembles were used to describe and map new EFH Level 2 information for this EFH 5-year Review.

Occupied habitat was defined as all locations where a species' life stage had probability of suitable habitat (GOA settled early juveniles) or encounter probability (all others) greater than 5%. Four areas were identified containing 95%, 75%, 50%, and 25% of the occupied habitat, where habitat is defined as areas exceeding a threshold of 5% predicted species encounter probability. The definition of EFH area in Alaska is the area containing 95% of the occupied habitat (NMFS 2005). Each of the lower quantiles (hereafter referred to as subareas) describes a more focused partition of the total EFH area. The area containing 75% of the occupied habitat based on SDM predictions is referred to as the "principal EFH area." For the fishing effects analysis of the 2017 EFH 5-year Review (EFH component 2; Simpson et al. 2017), the area containing 50% of the occupied habitat is termed the "core EFH area" and we have applied this terminology to our results. The areas containing the top 25% of the occupied area are referred to as "EFH hot spots". Mapping habitat percentiles for EFH subareas like these helps demonstrate the heterogeneity of fish and crab distributions over available habitat within the larger area identified as EFH and aligns our results with those of other EFH-related projects.

3.2.8.3 Species Complexes

Some groundfishes in Alaska are managed as members of stock complexes (e.g., the Other Rockfish Stock Complex in the Gulf of Alaska). While EFH must be designated for each managed species, EFH may be designated for assemblages of species with justification or scientific rationale provided (50 CFR 600.815(a)(1)(iv)(E)). In the present study, and for the first time in an EFH 5-year Review, we presented EFH descriptions of multi-species stock complexes using aggregated single species SDMs to produce descriptions of EFH to serve as proxies for individual species in the stock complex where an SDM EFH map was not possible due to data limitations (i.e., < 50 catches over the study period). To achieve this, we first generated multi-species abundance maps by summing the predicted abundances at each raster cell for each species in the complex that supported an ensemble. Then, using the same method described above for single species maps, we constructed an EFH map for the stock complex. In complexes where there was a mixture of available life history information (e.g., some species with known length-based life stage definitions and some without), life stages were combined for the species mapped together from the complex. See the introductory section of each species complex chapter (see section *Results*) for details about the species and life stages that were included.

3.2.8.4 EFH Comparisons between 2017 and 2022

The 2017 EFH 5-year Review used GAM and hGAM SDMs to predict species distributions in units of 4th root-transformed CPUE. For comparison with the 2022 ensembles, the 2017 predictions were converted into numerical abundance by raising them to the 4th power and dividing by the original fishing effort recorded during the RACE-GAP bottom trawl survey. This allowed the 2022 fit metrics (ρ, AUC, PDE) to be calculated for the 2017 SDMs (e.g., Table 9 and Table A2.2). In 2017, some species distributions were modelled using a type of MaxEnt SDM that is restricted to predicting probability and only AUC was calculated in these cases.

3.2.8.5 Bridging Figures

The changes from the maps produced for the 2017 EFH 5-year Review and those produced during the 2022 EFH 5-year Review were summarized in two ways. First, the 2017 EFH map was compared to the 2022 EFH map, and the percentage change in EFH areal extent was calculated (e.g., Figure 13). Second, the transition from the 2017 EFH map to the 2022 EFH map was broken into five steps to demonstrate the impact of specific advancements to the SDM methods (e.g., Figure 14).

Step one incorporated new life history information such as updated lengths at 50% maturity (L_{50}) into the data used to fit the SDM. This step was omitted if no new life history information was available. Step two incorporated any new data acquired during the RACE-GAP bottom trawl surveys from 2015–2019.

Step three incorporated all the advancements to the SDMs employed in the 2022 EFH 5-year Review. These include the following:

- The response variable changed from 4th root transformed CPUE (2017 EFH 5-year Review) to numerical abundance (2022 EFH 5-year Review).

- If the 2017 SDM was a GAM:
  - Step three changed from a Gaussian error distribution (2017) to either a Poisson or negative binomial distribution (2022).
  - The definition of occupied habitat was changed from all locations with positive CPUE (2017) to all locations with greater than 5% encounter probability (2022).
- If the 2017 SDM was a hGAM
  - The error distribution for the probability model was changed from a binomial distribution with a logit link (2017) to a binomial distribution with a cloglog link (2022).
  - The error distribution for the density model was changed from a Gaussian distribution (2017) to a zero-adjusted Poisson distribution (2022).
  - The definition for occupied habitat was changed from all locations with positive CPUE and with predicted encounter probability above an estimated threshold (2017), to all locations with greater than 5% encounter probability (2022).
  - The estimated threshold in 2017 was the probability that maximized sensitivity + specificity in a classification task, whereas 2022 used a consistent probability of 5%.
- If the 2017 SDM was a MaxEnt
  - The model changed from using the dismo package to fit a traditional maximum entropy model (2017) to using the maxnet package to fit it as an inhomogenous Poisson point process (2022).
  - The 2017 MaxEnt SDMs could not approximate numerical abundance, while this is possible in 2022.
  - The definition of occupied habitat changed from all locations with greater than 5% probability of suitable habitat (2017) to all locations with greater than 5% encounter probability (2022).

Step four added additional habitat covariates to the SDM. Lastly, step five used skill testing to make a weighted ensemble of multiple SDMs. At each step, the change in EFH area relative to the previous step was calculated.

3.2.8.6 EFH Level 3 Habitat Related Vital Rates

We advanced EFH information to Level 3 (habitat related vital rates) in the GOA for a set of groundfish species' settled early juvenile life stages to achieve a key Alaska EFH Research Plan objective for this EFH 5-year Review (Objective 2; Raise EFH level from 1 (distribution) or 2 (habitat-related densities or abundance) to Level 3 (habitat-related growth, reproduction, or survival rates); Sigler et al. 2017). This was done by integrating temperature-dependent vital rates developed from field and laboratory studies with SDM predictions of probability of suitable habitat. Temperature-dependent vital rates have been published or are in development for groundfish species in Alaska (Table 6). A representative example that can be applied in this context is from Laurel et al. (2016), who described the temperature-dependent growth rate of early juvenile Pacific cod as:

$$GR = y_0 + a * T + b * T^2 - c * T^3,$$

$$GR = 0.2494 + 0.3216 * T - 0.0069 * T^2 - 0.0004 * T^3$$

where *GR* is the growth rate expressed as the % change in body weight per day (% body weight per day), *T* is temperature in degrees-Celsius, and y_0, *a*, *b*, and *c* are estimated parameters. Species-specific vital rate formulations are detailed in each Results chapter where EFH Level 3 information was generated.

We constructed the EFH Level 3 maps by first mapping the temperature-dependent vital rates across the survey study area, using the CGOA ROMS 3 km bottom temperature covariate raster as the temperature value in the rate equations. Next, we computed the product of the rate map and the SDM-predicted probability of habitat map by multiplying the two rasters together. The product map was then transformed onto a relative scale ranging from zero to one, where zero indicates areas of low probability of suitable habitat and low habitat-related temperature-dependent growth potential and one indicates areas of high probability of suitable habitat and high habitat-related temperature-dependent growth potential. The Level 3 maps provide additional context when interpreting EFH Level 1 or Level 2 maps developed from the same SDMs.

3.2.9 Tables

Table 1. Comparison of species distribution model (SDM) data and methods in the present work with that of the 2017 EFH 5-year Review (e.g., Laman et al. 2017): RACE-GAP = NMFS Resource Assessment and Conservation Engineering Groundfish Assessment Program summer bottom trawl surveys; ADFG = Alaska Department of Fish and Game; MaxEnt = maximum entropy model, GAM = generalized additive model, hGAM = hurdle GAM, paGAM = presence-absence GAM.

SDM data and methods for the 2017 EFH Review	SDM data and methods for the 2022 EFH Review
Dependent variables	
RACE-GAP bottom trawl surveys through 2014	RACE-GAP bottom trawl surveys; 2015-2019 added
-	(GOA settled early juvenile life stage only) AFSC updated Nearshore Fish Atlas beach and purse seines, and small-mesh bottom trawls (1998-2019), and hook (1989-2019), juvenile sablefish hook-and-line survey (1985-2019)
-	(GOA settled early juvenile life stage only) ADFG small-mesh bottom trawl surveys (1989-2019)
-	(GOA settled early juvenile life stage only) AFSC juvenile sablefish tagging program hook-and-line (1985-2019)
-	Settled early juvenile life stage
Length-based life stages	Updated length-based life stages
Lengths at maturity through 2014	Updated lengths at maturity
Independent variables	
Bathymetry data through 2014	GOA bathymetry data updated through 2019
Slope (derived from bathymetry data through 2014)	GOA slope derived from bathymetry data through 2019
-	Bathymetric position index (BPI) derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Seafloor aspect northness and eastness derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Seafloor curvature derived from bathymetry data through 2014 (EBS and AI) and 2019 (GOA)
-	Rockiness (GOA and AI)
Sediment grain size (*phi)* data through 2014	Updated sediment grainsize (*phi)* data through 2019
Bottom temperature data through 2014	Updated bottom temperature through 2019

SDM data and methods for the 2017 EFH Review	SDM data and methods for the 2022 EFH Review
Bottom current data through 2014	Updated bottom currents
Bottom current variation through 2014	Updated bottom current variation
SDM methods	
Three possible SDMs selected *a priori* (either MaxEnt, hGAM, or GAM)	Five possible SDMs as constituents in an ensemble (MaxEnt, paGAM, hGAM, GAM_P, and GAM_{nb})
Use dismo package (Hijmans et al. 2017) to implement MaxEnt models	Use maxnet package (Phillips 2017) to implement MaxEnt models†
-	New paGAM using binomial distribution and cloglog link†
hGAM using binomial logit and Gaussian steps	hGAM using binomial cloglog and zero-adjusted Poisson steps
GAM using Gaussian distribution	Use Poisson and negative binomial distributions in GAM (GAM_P and GAM_{nb})
GAMs use 4th root transformed CPUE	GAMs use count data with effort offset
-	Settled early juveniles modeled (GOA only) using MaxEnt and species presence-only data from summer surveys of various gear-types (*see new dependent variables, above)*
Fit Metrics	
80% of data used to train model, 20% used to evaluate performance	Used 10-fold cross-validation to estimate ensemble weights
Best model chosen based on prevalence	SDMs skill tested and weighted based on inverse squared RMSE
AUC used to evaluate MaxEnt; Pearson r^2 used to evaluate GAMs	All SDMs evaluated with three metrics: Spearman's ρ, AUC, and PDE
EFH	
EFH area mapping method changed depending on model	EFH area mapping method is the same for all SDM ensembles
MaxEnt models EFH level 1, GAMs model EFH level 2	Almost all models can estimate approximate abundance and are EFH level 2*
†- Uses a complementary log-log (cloglog) link function and can be used to approximate numeric abundance * GOA settled early juveniles do not estimate abundance and should be considered EFH level 1	

Table 2. National Marine Fisheries Service (NMFS) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys, large marine ecosystems (LME) represented by each, and the data years included in the species distribution models for the 2017 EFH 5-year Review (*italics*) and added in the present study for the 2022 EFH 5-year Review (bold).

Survey Name	Large Marine Ecosystem	Data Years Included	Periodicity
Aleutian Islands*	Aleutian Island LME	*1991-2014* **2015-2019**	Triennial (1991-2000), Biennial (2000-present)
Eastern Bering Sea Shelf	Eastern Bering Sea LME	*1982-2014* **2015-2019**	Annual
Eastern Bering Sea Slope	Eastern Bering Sea LME	*2002,'04,'08,'10,'12* **2016**	Periodic
Gulf of Alaska	Gulf of Alaska LME	*1993-2013* **2015, 2017, 2019**	Triennial (1993-2001), Biennial (2001-present)
Northern Bering Sea	Arctic LME	*2010* **2017 and 2019**	Periodic

* For our analyses, we appended the western Gulf of Alaska portions of RACE-GAP summer bottom trawl surveys to the Aleutian Islands data set in interposing survey years to support the geographic split between the two LMEs at Unimak Pass.

Table 3. Catch data sources used to develop SDM of groundfish early juvenile life stages in the Gulf of Alaska (GOA), including location with GOA subregion indicated (western = w, central = c, eastern = e, and all = a), gear type, and years included; ADFG = Alaska Department of Fish and Game, AFSC = NMFS Alaska Fisheries Science Center, RACE-GAP = AFSC Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program.

Survey/ Source	Location	Gear Type	Years
RACE-GAP Summer Bottom Trawl Survey (von Szalay and Raring 2019)	GOAa, continental shelf	RACE Poly Nor'Eastern Bottom Trawl	1993-2019
ADFG Small-mesh Bottom Trawl Survey (Jackson and Ruccio 2003, Spalinger 2020)	GOAce, nearshore, continental shelf	Small-mesh bottom trawl (3.2 cm mesh)	1989-2019
AFSC updated Nearshore Fish Atlas of Alaska (Johnson et al. 2012; Grüss et al. 2021)	GOAa, coastal, nearshore	Beach seine, purse seine, small-mesh bottom trawl (3.2-32 mm mesh), hook-and-line	1998-2019
AFSC Sablefish Tagging Program (Echave et al. 2013)	GOAa, nearshore	Hook-and-line	1985-2020

Table 4. North Pacific groundfish species modeled to describe and map essential fish habitat (EFH) for the 2022 EFH 5-year Review with length-based life stage breaks (length units = mm) and survey region indicated where differences in life history information is documented. Life stage breaks updated since the 2017 EFH 5-year Review are indicated with bold text. (*rougheye and blackspotted rockfishes are modeled as a complex and apportioned separately).

Species Common Name	Early Juvenile	Subadult	Adult
Alaska plaice	**35**–140	**140–319** (≤ 280)	> 319 (> 280)
arrowtooth flounder	**35**–160	161–**480**	> **480**
flathead sole	**20**–140	AI: 141–**342**; EBS: 141–342 (≤ 250); GOA: 141–**333**	AI: > **343**; EBS: > 342 (> 250); GOA: > **333**
Greenland turbot	–	≤ **580** (≤ 650)	> **580** (> 650)
northern rock sole	**20**–140	AI: 141–**309**; EBS: 141–**309**; GOA: 141–**328**	AI: > **310**; EBS: > **310**; GOA: > **329**
yellowfin sole	**30**–140	141–296 (≤ 250)	> 296 (> 250)
Kamchatka flounder	–	**≤ 550**	**> 550**
Greenland turbot	–	**≤ 580**	**> 580**
Bering flounder	–	**≤ 238**	**> 238**
Petrale sole	–	**≤ 331**	**> 331**
English sole	**20 - 140**	**141 - 230**	**> 230**
Dover sole	**30 - 140**	**141 - 439**	**> 440**
rex sole	**70 - 140**	**141 - 352**	**> 352**
Sakhalin sole	--	**50 - 196**	**> 196**
starry flounder	GOA: **20 - 150**	BSAI: **≤ 350**; GOA: **151 - 350**	**> 351**
sand sole	**20 - 140**	**141 - 170**	**> 171**
southern rock sole	--	**≤ 347**	**> 348**
butter sole	--	**≤ 140**	**> 141**
Atka mackerel	--	**≤ 340**	**> 341**
sablefish	150–399	400–585 (≤ 400)	> 585 (> 400)
Pacific cod	40–150	BSAI: 151–**580**; GOA: 151–**503**	BSAI: > **580**; GOA: > **503**
walleye pollock	**40**–140	AI: 141–**381**; EBS: 141–**381**; GOA: 141–**410**	AI: > **381**; EBS: > **381**; GOA: > **410**

Species Common Name	Early Juvenile	Subadult	Adult
blackspotted rockfish	–	≤ 453 (≤ 430)	> 453 (> 430)
harlequin rockfish	–	≤ 188 (≤ 230)	> 188 (> 230)
northern rockfish	–	BSAI: ≤ 277 (≤ 250) GOA: ≤ **310**	BSAI: > 277 (> 250) GOA: > **310**
Pacific ocean perch	**25**–200	201–250 (≤ 250)	> 250
rougheye rockfish	–	≤ **430** (≤ 430)	> **430** (> 430)
shortspine thornyhead	--	**≤ 215**	**> 216**
longspine thornyhead	--	**≤ 178**	**> 179**
greenstriped rockfish	--	**≤ 220**	**> 221**
rosethorn rockfish	--	**≤ 215**	**> 216**
quillback rockfish	--	**≤ 290**	**> 291**
redstripe rockfish	--	**≤ 290**	**> 291**
yelloweye rockfish	--	**≤ 450**	**> 451**
redbanded rockfish	--	**≤ 420**	**> 421**
sharpchin rockfish	--	**≤ 250**	**> 251**
shortraker rockfish	--	**≤ 499**	**> 500**
spiny dogfish	–	**≤ 973**	**> 973**
big skate	–	**≤ 1486**	**> 1486**
Bering skate	–	**≤ 690**	**> 690**
longnose skate	–	**≤ 1131**	**> 1131**
mud skate	–	**≤ 595**	**> 595**
Alaska skate	–	**≤ 930**	**> 930**
Aleutian skate	–	**≤ 1320**	**> 1320**
whiteblotched skate	–	**≤ 964**	**> 964**

Table 5. Covariates used in habitat-based species distribution models (SDM) to fit (identify best fitting formulation) and then predict distributions and abundances from the final ensembles or final model of North Pacific groundfish and crab species to describe essential fish habitat (EFH) in Aleutian Islands (AI), Gulf of Alaska (GOA), and eastern Bering Sea (EBS). Covariates applied to SDMs are indicated by region (columns) and life stage (in parentheses under regions; settled early juvenile = EJ; subadult = SA; and adult = A). X's in the region columns indicate that covariates were used for every life stage.

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Bottom temperature	°C	Mean bottom temperatures measured on bottom trawls during AFSC RACE-GAP summer trawl surveys (1982–2019)	Empirical Bayesian kriging	Temperature data collected at bottom trawl hauls	x	SA, A	x
Bottom temperature (modeled)	°C	Bottom temperature (deepest depth bin) predicted from the CGOA ROMS 3 km grid (Coyle et al. 2019) from May-September and averaged (1999–2019).	Natural neighbor	Modeled temperature data from CGOA ROMS 3 km	--	EJ	--
Bottom current Northing and Easting	m·sec-1	Seafloor ocean current components predicted from the NEP5 ROMS (Danielson et al. 2011) averaged for the bottom layer across summer years (1991–2018)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom current	x	SA, A	--
Bottom current Northing and Easting	m·sec-1	Seafloor ocean current components predicted from the Bering10K ROMS (Kearney et al. 2020) averaged for the bottom 5m across summer years (1982–2019)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom 5m current	--	--	x
Bottom current Northing and Easting variability	m·sec-1	Pooled standard deviation of seafloor ocean current components predicted from the NEP5 ROMS (Danielson et al. 2011) averaged for the bottom layer across summer years (1991–2018)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom current pooled standard deviation	x	SA, A	--
Bottom current Northing and Easting variability	m·sec-1	Pooled standard deviation of seafloor ocean current components predicted from the Bering10K ROMS (Kearney et al. 2020) from the bottom 5m across summer years (1982–2019)	Inverse distance weighting	Training: mean towpath value Prediction: raster of bottom 5m current pooled standard deviation	--	--	x
Maximum tidal current	cm·sec-1	Predicted tidal current maximum at each bottom trawl location over a lunar year cycle (Egbert and Erofeeva 2002)	Ordinary kriging	Training: mean towpath value Prediction: kriged surface of tidal maxima	x	x	x
Geographic Location	Latitude, Longitude	Midpoint of bottom trawl hauls corrected for position of the trawl net relative to the vessel in Alaska Albers Equal Area conic projection	--	Training: position collected during bottom trawl hauls. Prediction: raster of positions	x	SA, A	x
Bottom Depth	meters (m)	Bathymetry of the seafloor based on acoustic seafloor mapping data and digitized, position corrected NOS charts	Natural neighbor	Training: mean bottom depth of trawl Prediction: raster of bathymetry soundings data	x	x	x

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Slope	degrees	Maximum gradient in depth between adjacent cells, derived from bathymetry (Horn 1981) applied with Benthic Terrain Modeler in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of slopes derived from bathymetry	x	x	x
Bathymetric Position Index	--	Relative difference of elevation between neighboring locations, illustrates bathymetric highs and lows across the landscape, derived from bathymetry (Guisan et al. 1999) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of bathymetric position index derived from bathymetry	x	x	x
Aspect Eastness and Northness	--	Describes concavity/convexity as well as sloping nature, derived from bathymetry (Horn 1981) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of aspect derived from bathymetry	x	x	x
Curvature	--	Combined plan and profile curvature to return "standard" curvature; derived from bathymetry (Schmidt et al. 2003) applied in ArcGIS (Walbridge et al. 2018)	--	Training: mean towpath value Prediction: raster of curvature derived from bathymetry	x	x	x
Rockiness	--	Continuous surface of compiled datasets representing locations of rocky and not rocky substrate (updated from Pirtle et al. 2019)	Natural neighbor	Training: mean towpath value Prediction: raster of seafloor rockiness.	x	x	--
Sediment grain size	*phi*	Sediment grain size derived from sampling in the eastern Bering Sea and curated in the EBSSED2 database (Richwine et al. 2018)	Ordinary kriging	Training: mean towpath value Prediction: kriged surface of sediment grain size	--	--	x
Coral presence or absence	probability	Coral presence-absence in bottom trawl catches / model-predicted coral presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of corals in trawl catches Prediction: Raster of model-predicted binary presence-absence of coral (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x
Sponge presence or absence	probability	Sponge presence-absence in bottom trawl catches / model-predicted sponge presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of sponge in trawl catches Prediction: Raster of model-predicted binary presence-absence of sponge (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x

Variable	Unit	Description of Prediction Raster	Interpolation method	Data Source and Usage	AI	GOA	EBS
Pennatulacean presence-absence	probability	Pennatulacean presence-absence in bottom trawl catches / model-predicted penn. presence-absence (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	--	Training: presence-absence of pennatulaceans in trawl catches Prediction: Raster of model-predicted binary presence-absence of pennatulaceans (Rooper et al. 2014, 2016, 2017; Sigler et al. 2015)	x	x	x

Table 6. Groundfish species in the Gulf of Alaska and life stages for which vital rates are available from the literature or ongoing studies; combining these vital rates with EFH will advance EFH information to Level 3. Settled early juvenile = EJ.

Species	Life Stage	Region	Vital Rate
walleye pollock	age-0, EJ	AI [a, b], GOA [a, b, c]	growth [a], lipid accumulation (condition) [b], winter energy loss (condition) † [c]
Pacific cod	age-0, EJ	EBS [a, b], GOA [a, b]	growth [a], lipid accumulation (condition) [b]
sablefish	EJ	GOA	growth [d]
yellowfin sole	EJ	GOA	growth [e]
northern rock sole	EJ	GOA	growth [e]
Pacific ocean perch	EJ	GOA	growth [f]

[a] Laurel et al. 2016, [b] Copeman et al. 2017, [c] Laurel et al. *in prep*, [d] Krieger et al. 2019, [e] Hurst *in prep*, [f] Rooper et al. 2012. † Addressed by Laurel et al. *in prep* for the 2022 EFH Review.

3.2.10 Figures

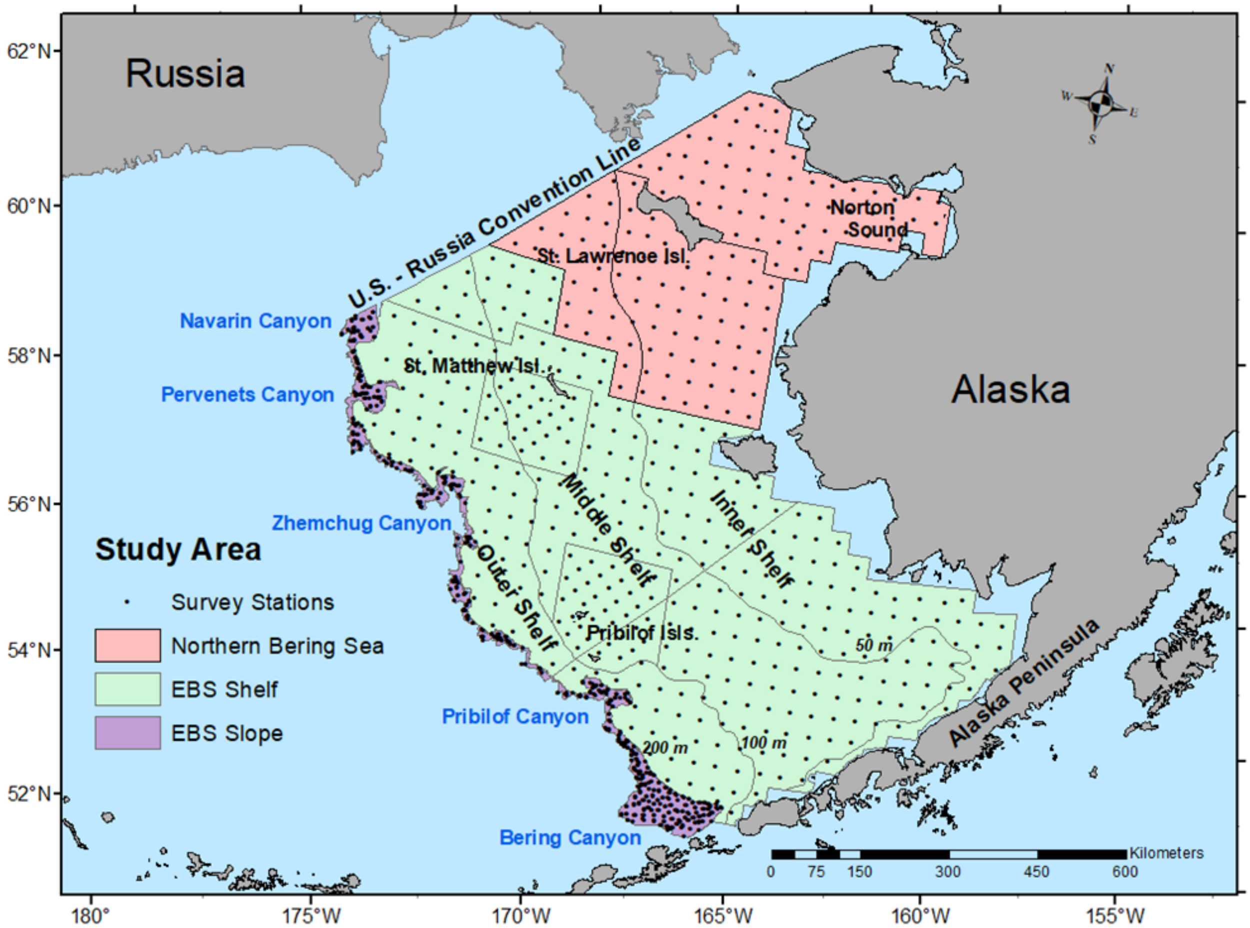

Figure 2. Eastern Bering Sea (EBS) from the Alaska Peninsula to the northern Bering Sea where this modeling study was conducted. Dots indicate the locations of bottom trawl stations from the eastern Bering Sea shelf annual bottom trawl survey (1982–2019), the eastern Bering Sea slope biennial bottom trawl survey (2002-2016), and the northern Bering Sea survey (2010, 2017, 2019) showing the 50 m, 100 m, and 200 m isobaths.

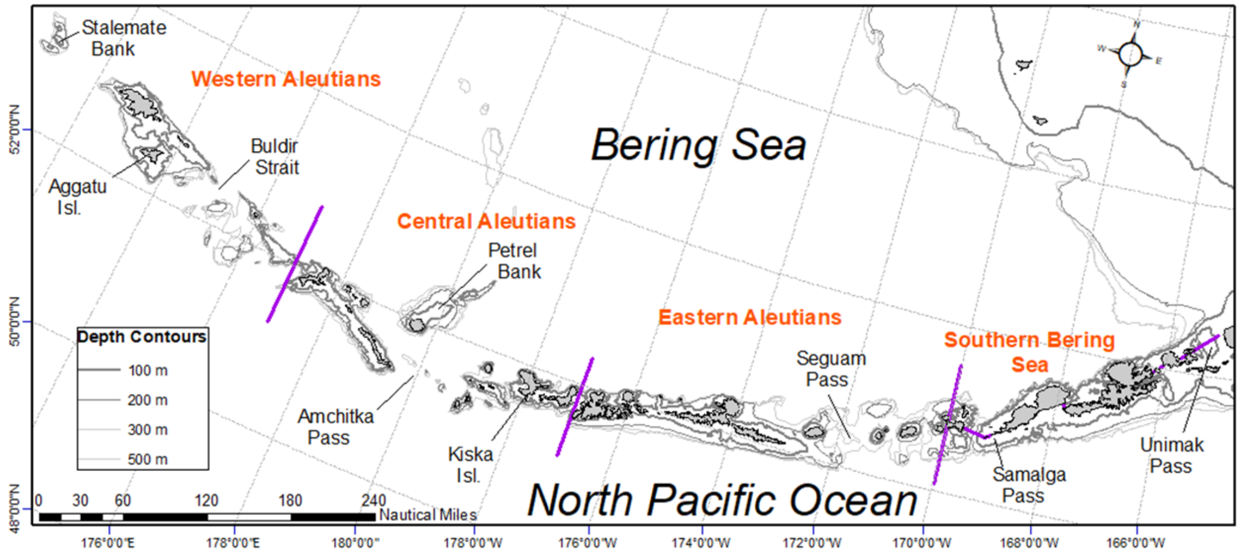

Figure 3. Aleutian Islands (AI) from Unimak Pass to Stalemate Bank where data for this modeling study were collected on Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys (1991-2019).

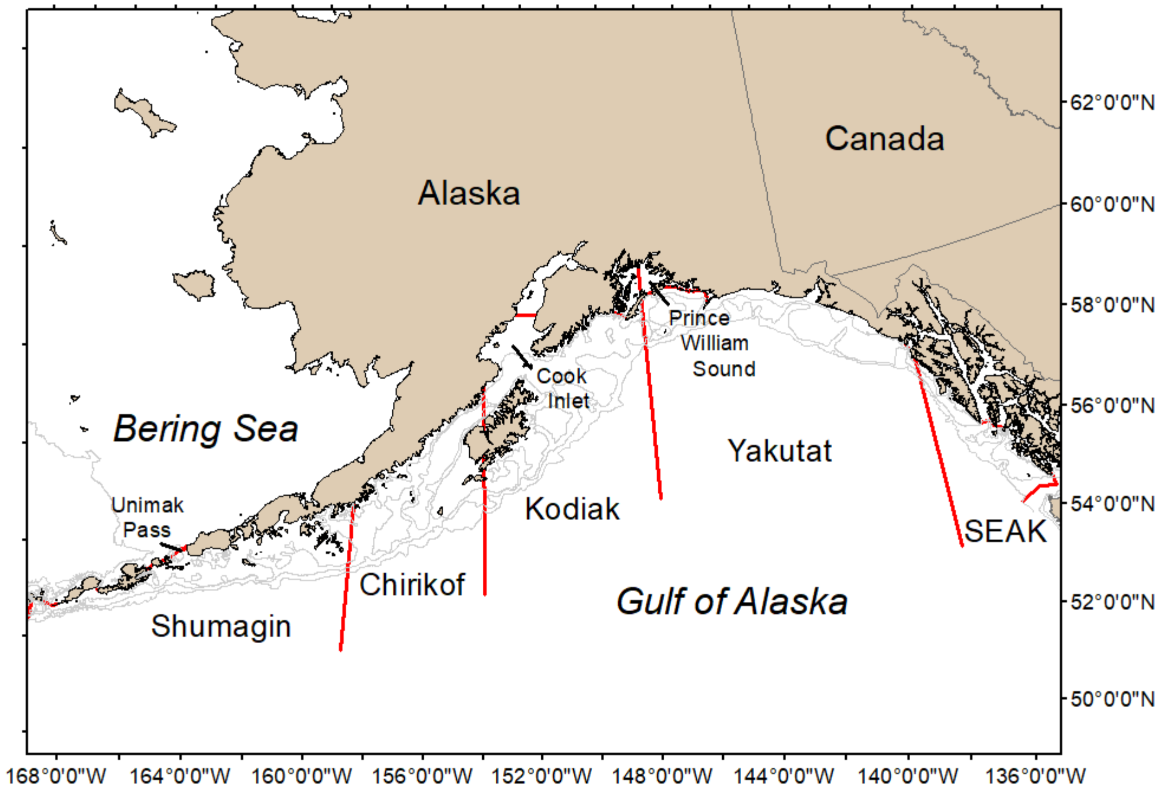

Figure 4. Gulf of Alaska (GOA) from Unimak Pass to Dixon Entrance where data for this modeling study were collected on Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering-Groundfish Assessment Program (RACE-GAP) summer bottom trawl surveys (1993-2019).

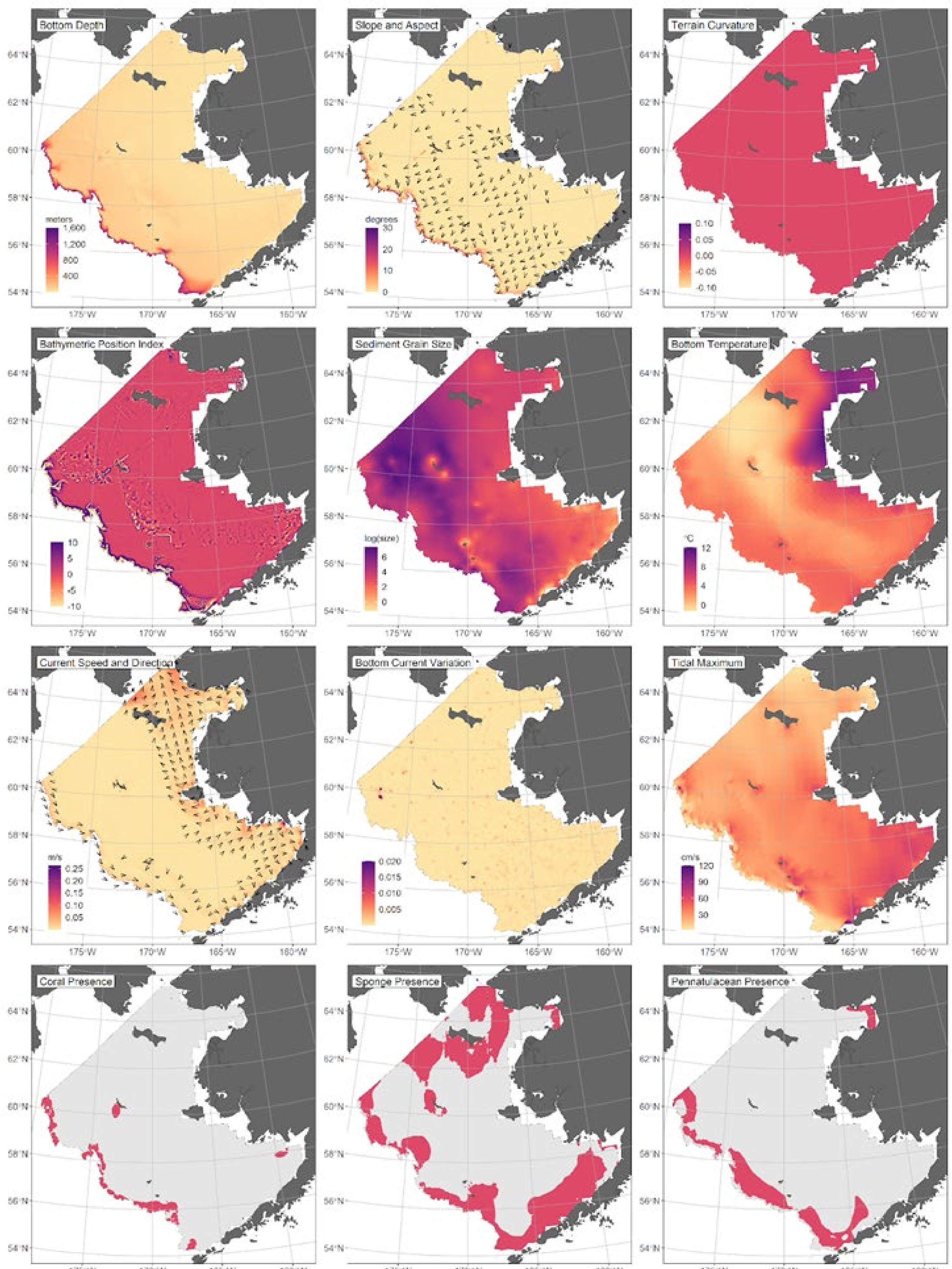

Figure 5. Maps showing the covariates used in the 2022 EFH 5-year Review of the EBS. “Slope and Aspect" and “Current Speed and Direction” are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

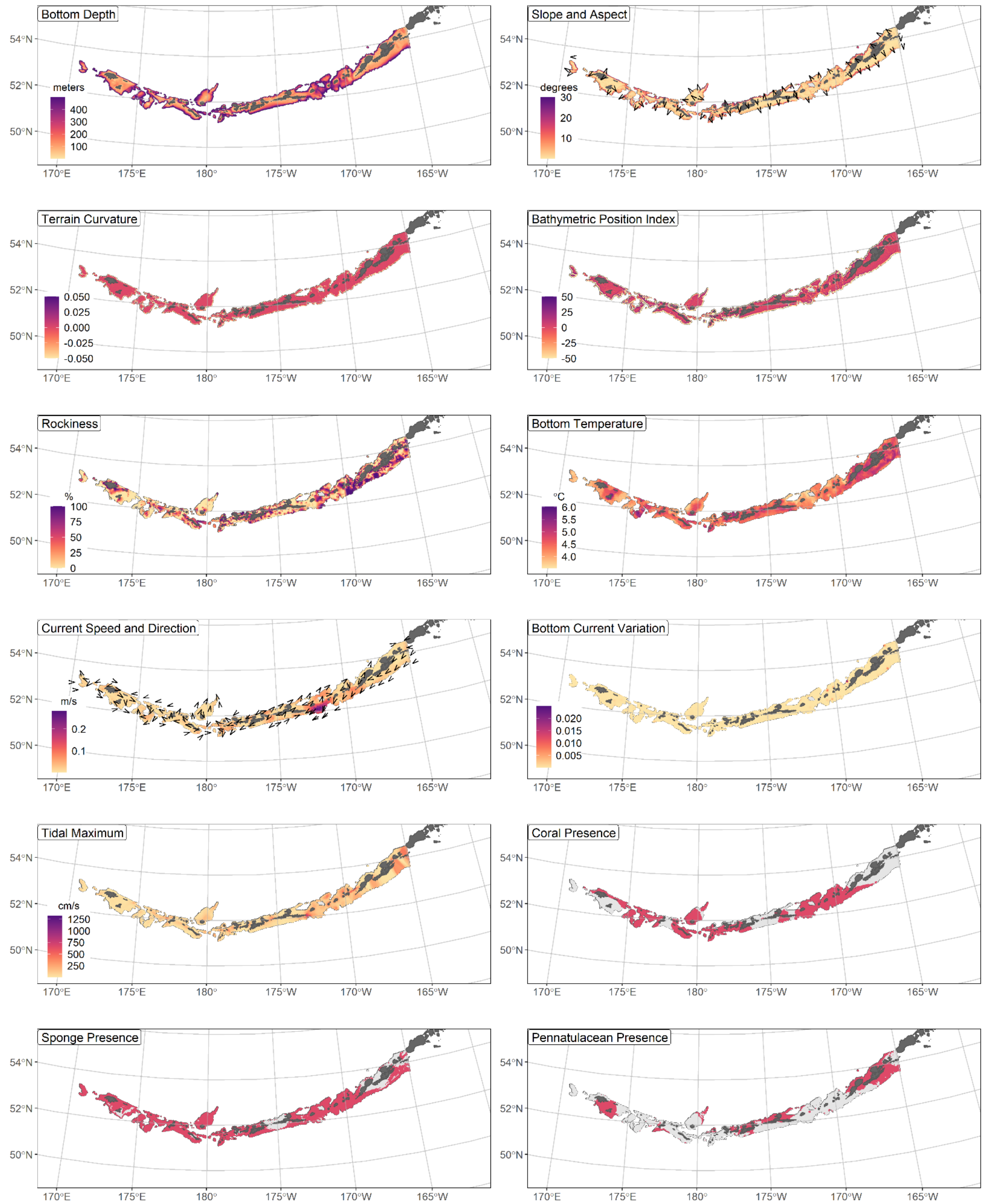

Figure 6. Maps showing the covariates used in the 2022 EFH 5-year Review of the AI. The AI maps include data from the GOA survey west of Unimak Pass. "Slope and Aspect" and "Current Speed and Direction" are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

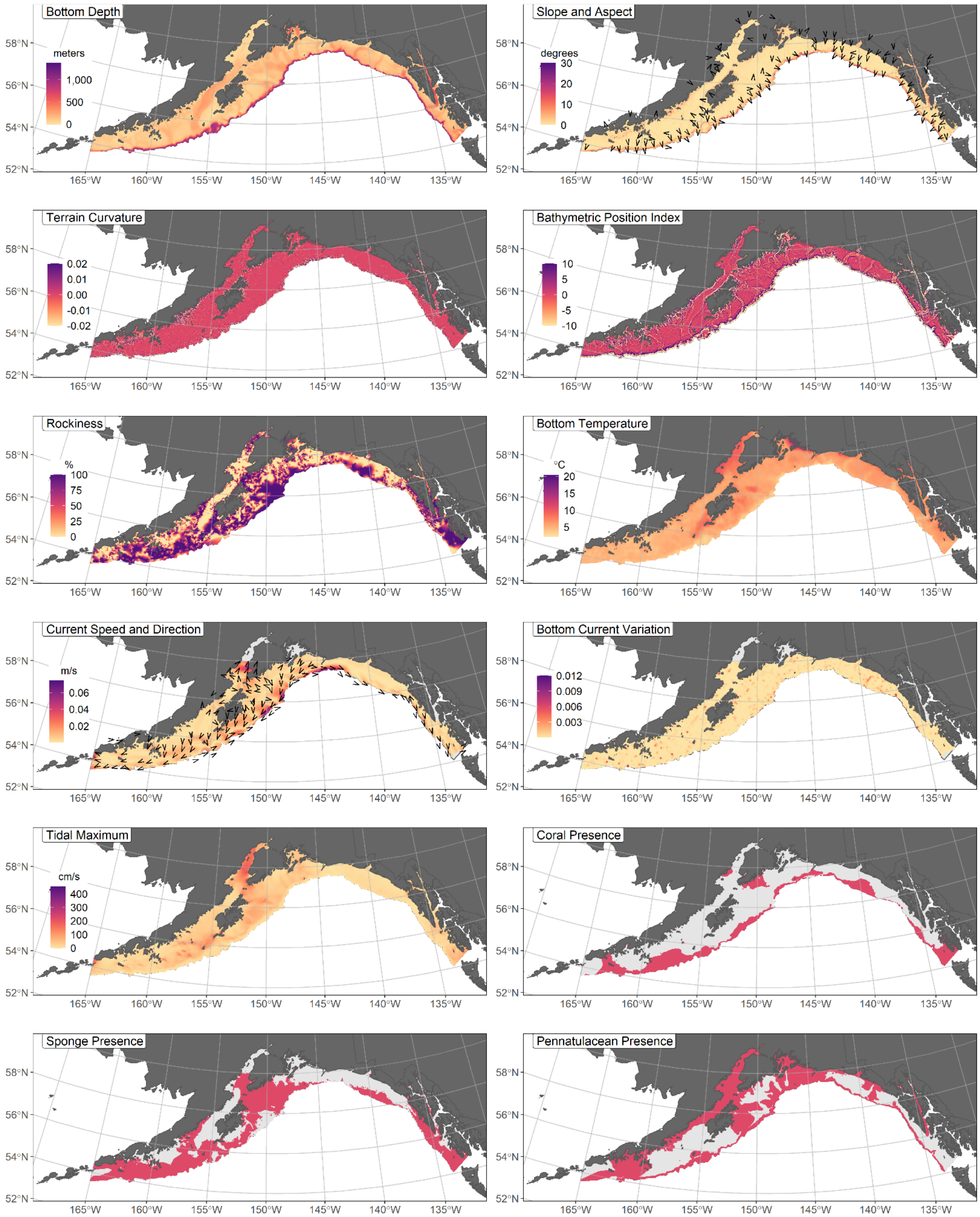

Figure 7. Maps showing the covariates used in the 2022 EFH 5-year Review of the GOA. Data from the GOA survey area west of Unimak Pass has been removed and is included in the AI. "Slope and Aspect" and "Current Speed and Direction" are vectors composed of multiple components and the color indicates the magnitude of the vector and the arrows show the direction. Locations with values of zero are not marked with an arrow. Structure forming invertebrates (coral, sponge, and pennatulaceans) are shown in the bottom row and the colored areas indicate where they are present.

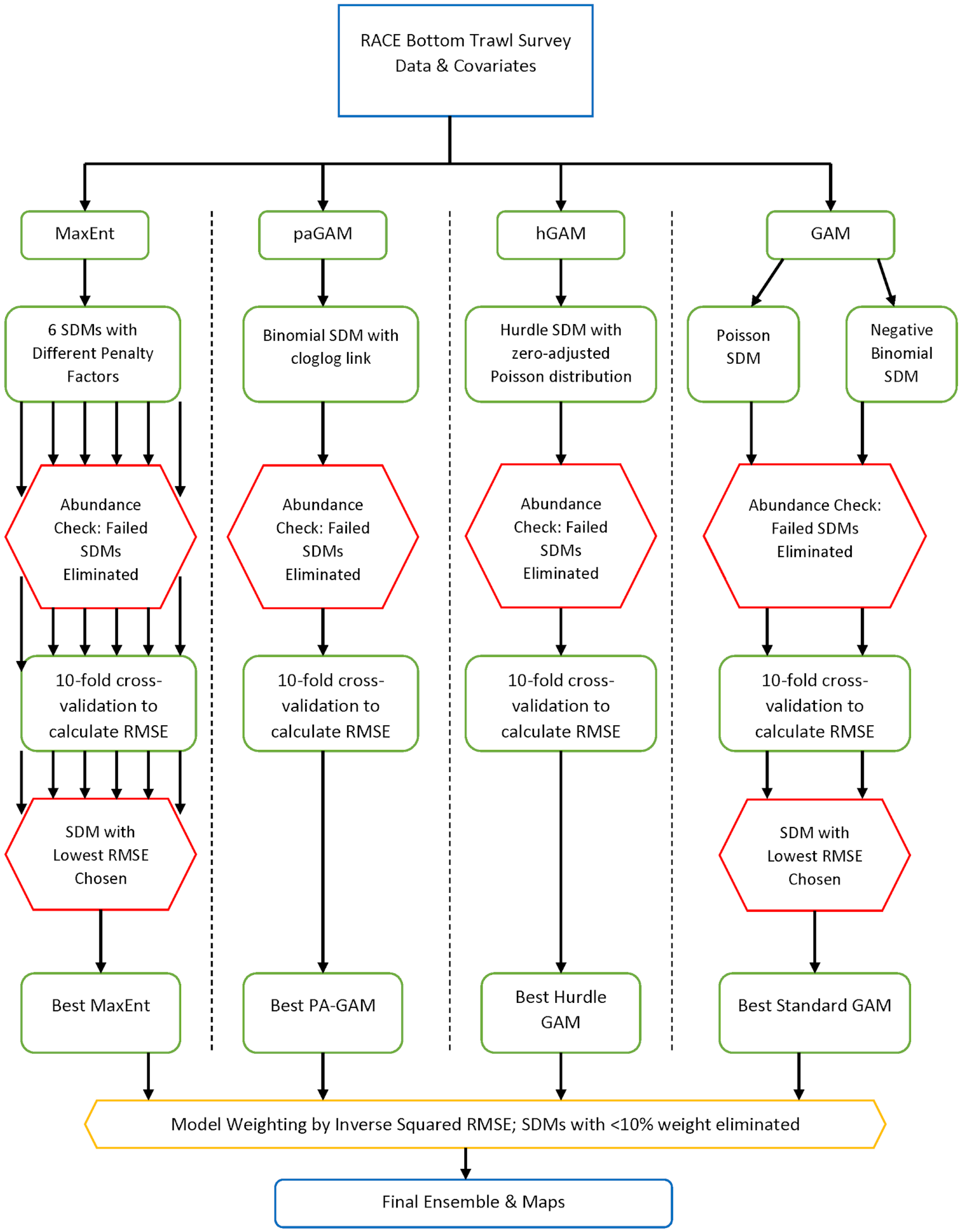

Figure 8. Pathways to formulation and assessment of five species distribution models (MaxEnt = maximum entropy, paGAM = presence-absence generalized additive model, hGAM = hurdle GAM, GAM_P = standard Poisson GAM, GAM_{nb} = standard negative-binomial GAM) for inclusion in or elimination from a final ensemble predicting habitat-related distribution and abundance used to describe and map essential fish habitat (EFH) in Alaska: RMSE = root mean square error.

3.3 Results

The Laman et al. study has demonstrated a revised SDM ensemble EFH approach for the 2022 EFH 5-year Review, where EFH is described and mapped for 32 North Pacific groundfish species in the EBS, 25 in the AI, 42 in the GOA across up to three life stages. In addition, EFH is described for five crabs in the EBS, two crabs in the AI, and octopus in all three regions.

This results section presents case studies for a selection of species' life stages modeled by this study in the EBS, AI, and GOA with new or revised EFH maps and bridging comparisons between the 2017 and 2022 EFH maps. The complete set of results for each species' life stage modeled by this study for the 2022 EFH 5-year Review are provided in the attached Technical Memoranda (Attachments 3-5) and summarized in Appendix 2 (5.2). Comparisons between the 2017 and 2022 EFH maps are summarized in Appendix 3 (5.3). The full set of the 2017 and 2022 EFH map overlay figures are provided in Attachment 2 and examples are presented in the three case studies in this section. Appendix 4 (5.4) is expanded reporting of additional performance metrics considered in the present work and requested for consideration by the SSC (Appendix 1 Table A1.1 items 6j and k). A Synthesis subsection concludes the Laman et al. study results section and draws from the results summaries and comparisons in the Appendices (5).

3.3.1 EFH Levels Advancements

Updates to data and methods used during the 2022 EFH 5-year Review have resulted in advancements in the EFH Level for many species' life stages (Table A3.1). This information is provided as an outcome of an EFH 5-year Review (e.g., Simpson et al. 2017) and SSC requested a summary of EFH Level advancements in the 2022 EFH 5-year Review for the February 2022 SSC review of EFH component 1 (Table A1.1 item 6e). EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence, EFH Level 2 with a model that can also predict abundance or density, and EFH Level 3 where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **The following EFH Level advancements are available for the 2022 5-year Review—**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 has not changed. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2022 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2022, although the data and methods were updated and revised in the 2022 ensemble approach to mapping EFH.
- For the first time, EFH Level 2 models were combined for member species of each of 7 stock complexes in the BSAI (4) and GOA (3) groundfish FMPs to represent the EFH of member

species where a model was not possible at this time (i.e., fewer than 50 positive survey catches were available)[40].

A total of 229 new and revised EFH descriptions and maps for the BSAI, GOA, and Crab FMPs are available for the 2022 EFH 5-year Review—

- New EFH Level 1 descriptions and maps for settled early juvenile life stages in the GOA FMP (11).
- New and revised EFH Level 2 descriptions maps for the BSAI (115), GOA (76), and Crab (7) FMPs (200).
- New EFH Level 2 descriptions and maps for stock complexes as a proxy for member species where a model was not possible at this time for the BSAI (6) and GOA (4) FMPs (10).
- New EFH Level 3 descriptions maps for settled early juvenile life stages (BSAI (2) and GOA (6) FMPs = 8).

3.3.2 Regional Case Studies

Case studies are presented demonstrating the revised SDM EFH approach by the Laman et al. study for the 2022 EFH 5-year Review. Three case studies are new and revised EFH Level 2 maps with bridging comparisons between 2017 and 2022. These case studies include the full set of results for one species' life stage in each region and were selected as examples of EFH area decreasing between 2017 and 2022 (arrowtooth flounder adults in the eastern Bering Sea), increasing (golden king crab life stages in the Aleutian Islands), and remaining relatively even (Pacific cod adults in the Gulf of Alaska). A final case study presents Pacific cod settled early juveniles in the GOA to demonstrate new EFH Level 1 and Level 3 maps for this life stage in that region.

3.3.2.1 Arrowtooth flounder adults in the Bering Sea

Arrowtooth flounder (*Atheresthes stomias*, ATF) is a large-bodied flatfish that can be found from the Kuril Islands in the western Pacific Ocean to California in the east (Orlov 2004). In the Bering Sea, ATF occur over the continental shelf (Shotwell et al. 2020) and along the edge of the continental slope, particularly in the south and southeast, possibly reflecting spawning along the shelf break (Doyle et al. 2018) and their tendency to avoid colder temperatures (Spencer 2008). The majority of female ATF become sexually mature around 480 mm F.L. in the EBS (L_{50}; Stark 2012), though age at maturity can vary considerably across regions (Spies et al. 2018). This species is highly predatory and is thought to be an important part of the marine food web. In particular, it is a major predator of juvenile walleye pollock (*Gadus chalcogrammus*; Yang and Livingston 1986).

Adult ATF were widely distributed across the middle and outer shelf domains in EBS RACE-GAP summer bottom trawl survey catches (1992–2019; Figure 9). We considered five constituent SDMs to include in the ensemble predicting numerical abundance of adult ATF in the EBS (Table 7), but the GAM_{nb} was eliminated in favor of the GAM_P. Four models were included in the final ensemble. The MaxEnt and hGAM were given less weight than the paGAM or GAM_P. Overall, the ensemble fit to observed adult ATF distribution and abundance was excellent. The ensemble was excellent at predicting catches of high and low adult ATF abundance (ρ = 0.81), presence-absence (AUC = 0.96), and at explaining deviance (PDE = 0.64). Geographic location, bottom temperature, and bottom depth accounted for 84% of the deviance explained by the ensemble predicting adult ATF numerical abundance (Table 8). Adult abundance was highest in the southern EBS over the middle shelf and shelf break as well as along the shelf break in the north near the heads of Navarin and Pervenets Canyons at depths between 300 and 400 m at bottom water temperatures greater than 5°C (Figure 10). The CVs of predicted abundance were

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high over the middle shelf domain of the EBS. Encounter probabilities for adult ATF were high in Bristol Bay, along the southern middle shelf domain, and northward along the outer shelf domain to the northwestern extent of the survey area (Figure 11).

Habitat-related ensemble-predicted numerical abundance of ATF life stages collected in RACE-GAP summer bottom trawl surveys of the EBS (1992–2019) was translated into EFH areas and additional habitat-related subareas (Figure 12). The EFH area for adult ATF was focused over the middle and outer shelf domains with core EFH area and EFH hot spots in deeper waters.

Table 7. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for adult arrowtooth flounder: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; and GAM_{nb} = standard negative-binomial GAM. Ensemble performance (ρ = Spearman's rank correlation coefficient), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE) were generated from 10-fold cross-validation. The presence of "--" in a field indicates that this value was not calculated because the corresponding model was eliminated from the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	36.1	0.16	0.81	0.96	0.37	333,000
paGAM	28.1	0.26	0.81	0.96	0.58	456,900
hGAM	27.0	0.29	0.81	0.96	0.63	389,800
GAM_P	26.9	0.29	0.80	0.95	0.63	403,800
GAM_{nb}	27.4	0	--	--	--	--
ensemble	26.6	1	0.81	0.96	0.62	426,400
* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.						

Table 8. Covariates retained in the adult arrowtooth flounder species distribution model (SDM) final ensemble, the percent contribution to the ensemble deviance explained by each, and the cumulative deviance explained: *phi* = sediment grain size, SD = standard deviation, and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
geographic location	30.4	30.4
bottom temperature	28.7	59.2
bottom depth	24.9	84.0
current	6.5	90.5
slope	3.1	93.6
phi	2.5	96.1
current SD	1.0	97.1
BPI	0.7	97.8
aspect northness	0.4	98.2
tidal maximum	0.4	98.6
pennatulacean presence	0.4	99.0
curvature	0.4	99.4
sponge presence	0.3	99.7
aspect eastness	0.2	99.9
coral presence	0.1	100.0

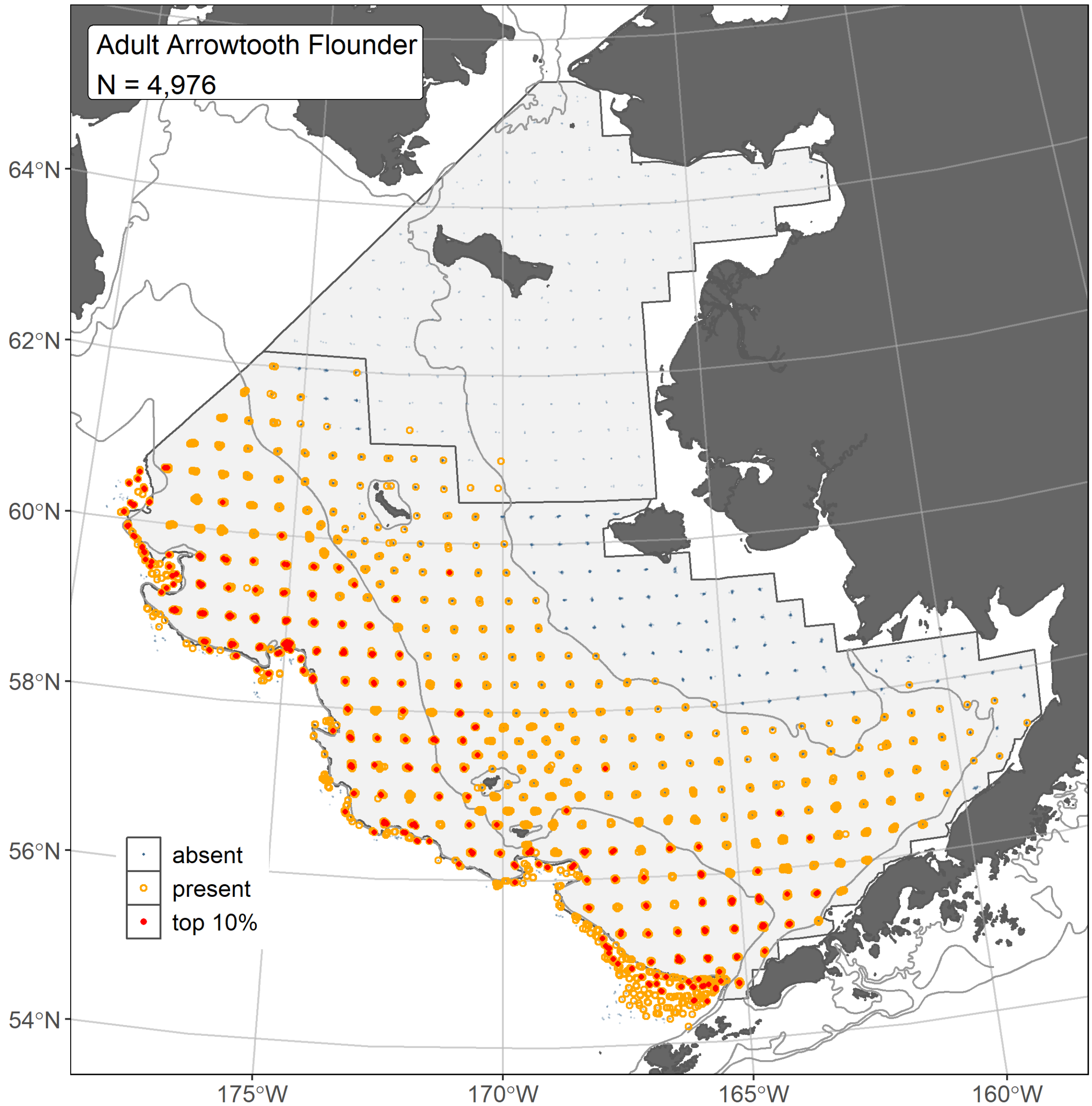

Figure 9. Distribution of adult arrowtooth flounder catches (N = 4,976) in 1992–2019 AFSC RACE-GAP summer bottom trawl surveys of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated; filled red circles indicate catches in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

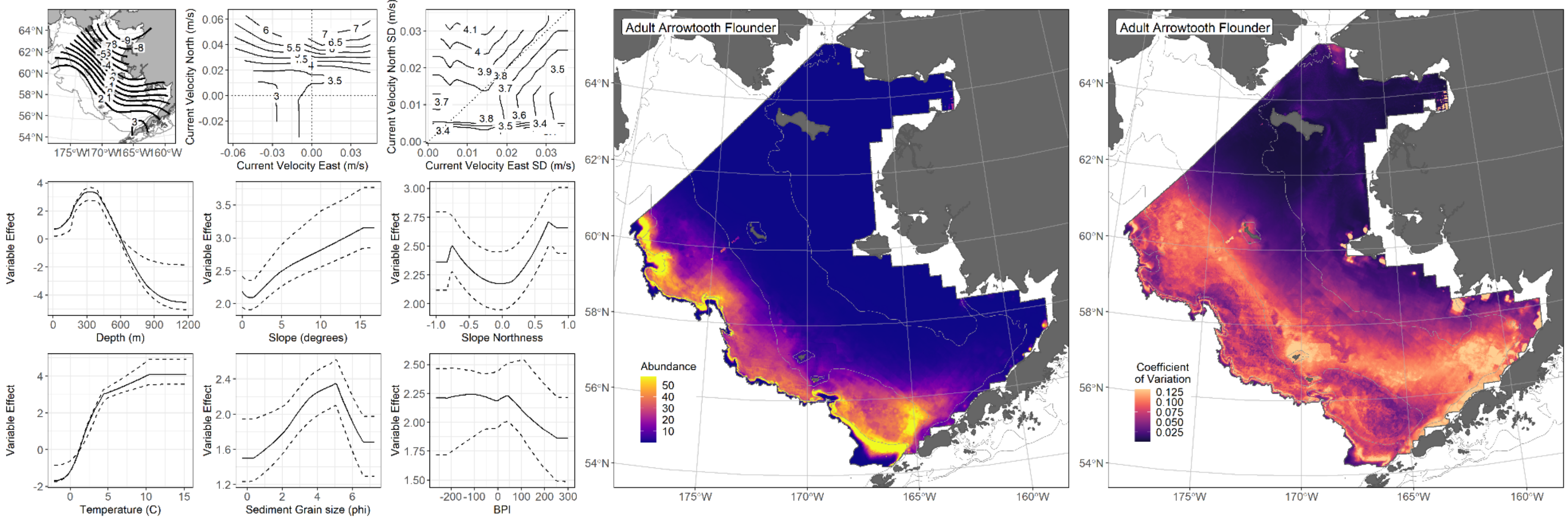

Figure 10. The top nine covariate effects (left panel) on ensemble-predicted adult arrowtooth flounder numerical abundance across the eastern Bering Sea Shelf, Slope, and Northern Bering Sea (center panel) alongside the coefficient of variation (CV) of the ensemble predictions (right panel).

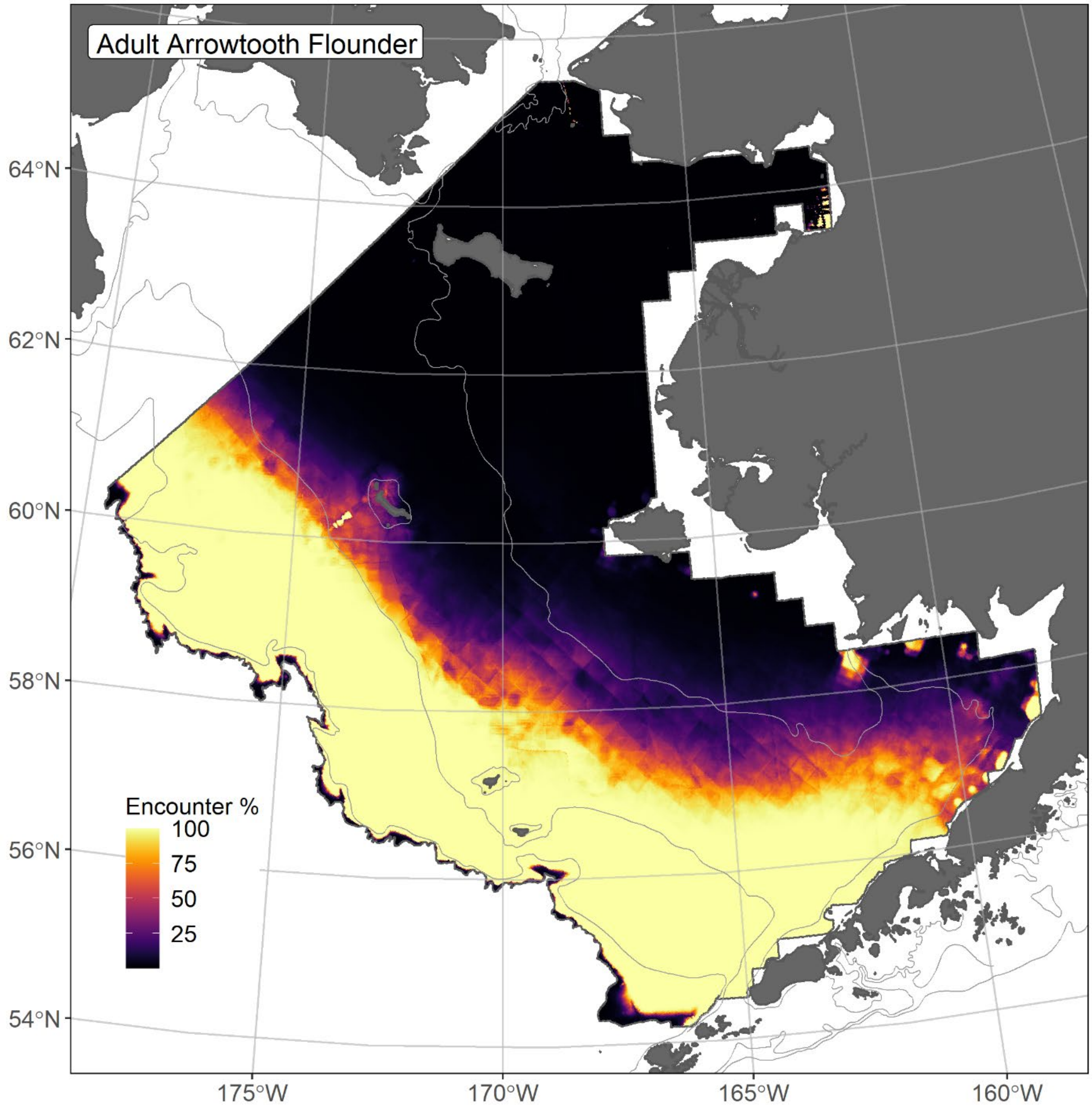

Figure 11. Encounter probability of adult arrowtooth flounder from AFSC RACE-GAP summer bottom trawl surveys (1992–2019) of the eastern Bering Sea Shelf, Slope, and Northern Bering Sea with the 50 m, 100 m, and 200 m isobaths indicated.

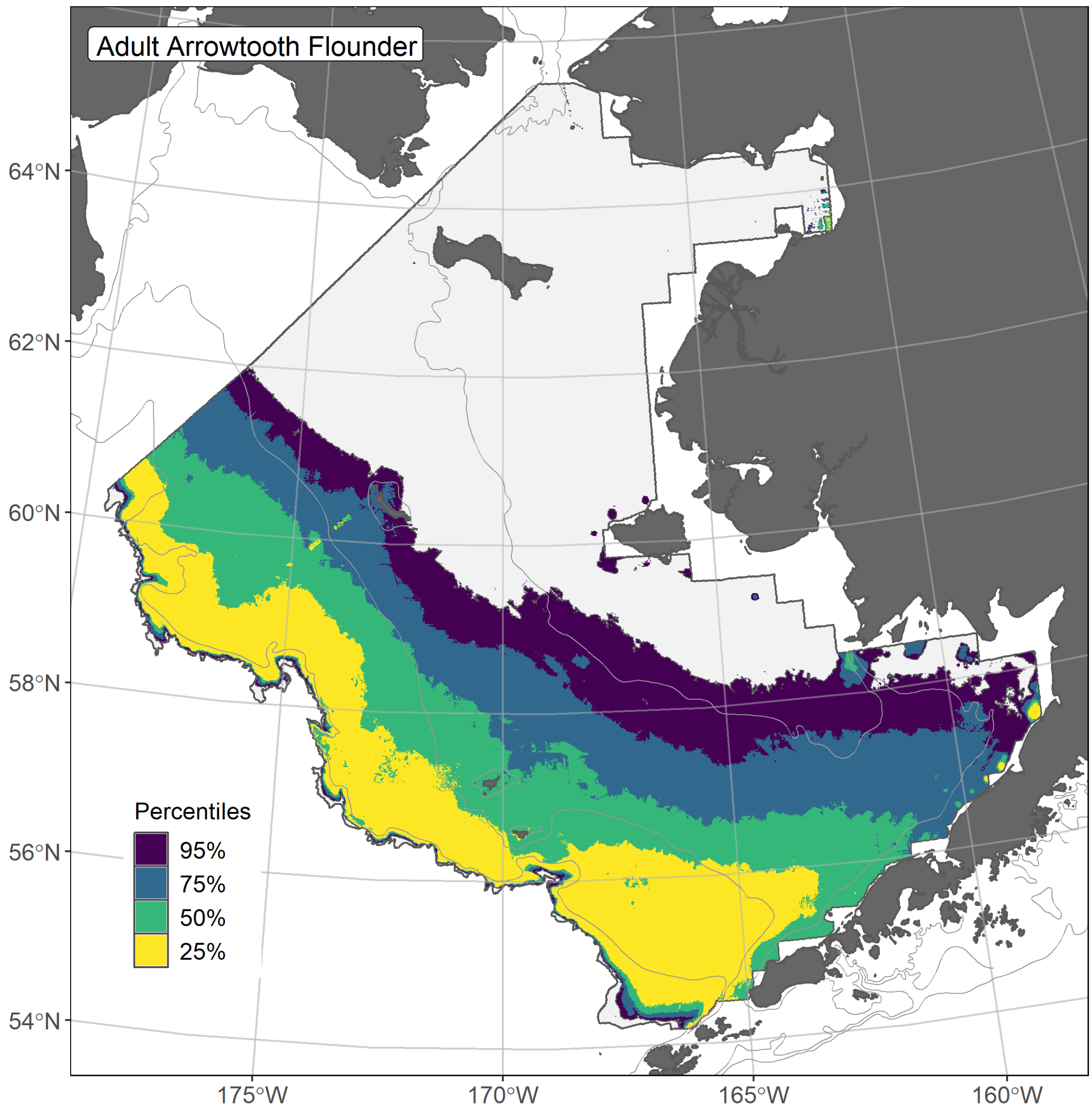

Figure 12. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to adult arrowtooth flounder distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance.

3.3.2.2 Bridging the 2017 and 2022 EFH designations for adult arrowtooth flounder in the Bering Sea

The new ensemble produced for the 2022 5-year Review for adult arrowtooth flounder in the Bering Sea showed improved performance relative to the 2017 model (Table 9). The RMSE of the 2022 ensemble was much lower, suggesting more precision in abundance predictions. While the scores for ρ and AUC were nearly identical, the 2022 ensemble showed improvement in terms of deviance explained (PDE). Taken together, these metrics suggest that the new 2022 SDM ensemble is an improvement over the SDM from the 2017 EFH 5-year Review.

The changes implemented during the 2022 EFH review resulted in 15.5% reduction in adult arrowtooth flounder EFH area from 504,500 km^2 in 2017 to 426,400 km^2 in 2022 (Table 9, Figure 13). Most of the reduction was attributable to the elimination of almost all of the northern Bering Sea from the arrowtooth flounder EFH, though this was partially offset by the addition of some areas in Bristol Bay and the inner continental shelf. The 2022 EFH map better corresponded to the observed spatial distribution of trawl catches for this species than the 2017 map (Figure 9), and the reduction in EFH area reflected improvements to the SDM process.

Refinements to our modeling approach altered EBS adult ATF EFH relative to the 2017 areal extent (Figure 14). Panel A shows the original EFH designation for adult arrowtooth flounder produced during the 2017 cycle. In panel B, updating the length-based life stage definition separating subadults from adults from 350 mm (Zimmermann 1997) to 480 mm (Stark 2012) resulted in minor changes to the EFH areal extent. In panel C, the addition of 5 more years of bottom trawl survey data, including 874 new catches of ATF, had little effect on the EFH description. In panel D, shifting to the prediction of numerical abundance as the response variable and updating the EFH definition resulted in a 25.1% reduction in total area extent and the removal of all locations in the northern Bering Sea from the EFH description. In panel E, the addition of new terrain and bottom current covariates caused a small shift in overall area with the inclusion of the middle shelf Bristol Bay. Finally, in panel F, the creation of the ensemble from four SDMs described a small further extension of EFH into Bristol Bay.

Table 9. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2022 5-year Reviews of EBS adult arrowtooth flounder. The metrics presented are number of positive catch hauls (N), root-mean-square-error (RMSE), Spearman's rank correlation coefficient (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2022. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM Method	N	RMSE	ρ	AUC	PDE	EFH Area	Core EFH Area	% Change in Area
2017	GAM_{CPUE}	4,102	83.9	0.82	0.95	0.45	504,500	265,500	--
2022	Ensemble	4,976	26.6	0.81	0.96	0.64	426,400	224,400	-15.5 %

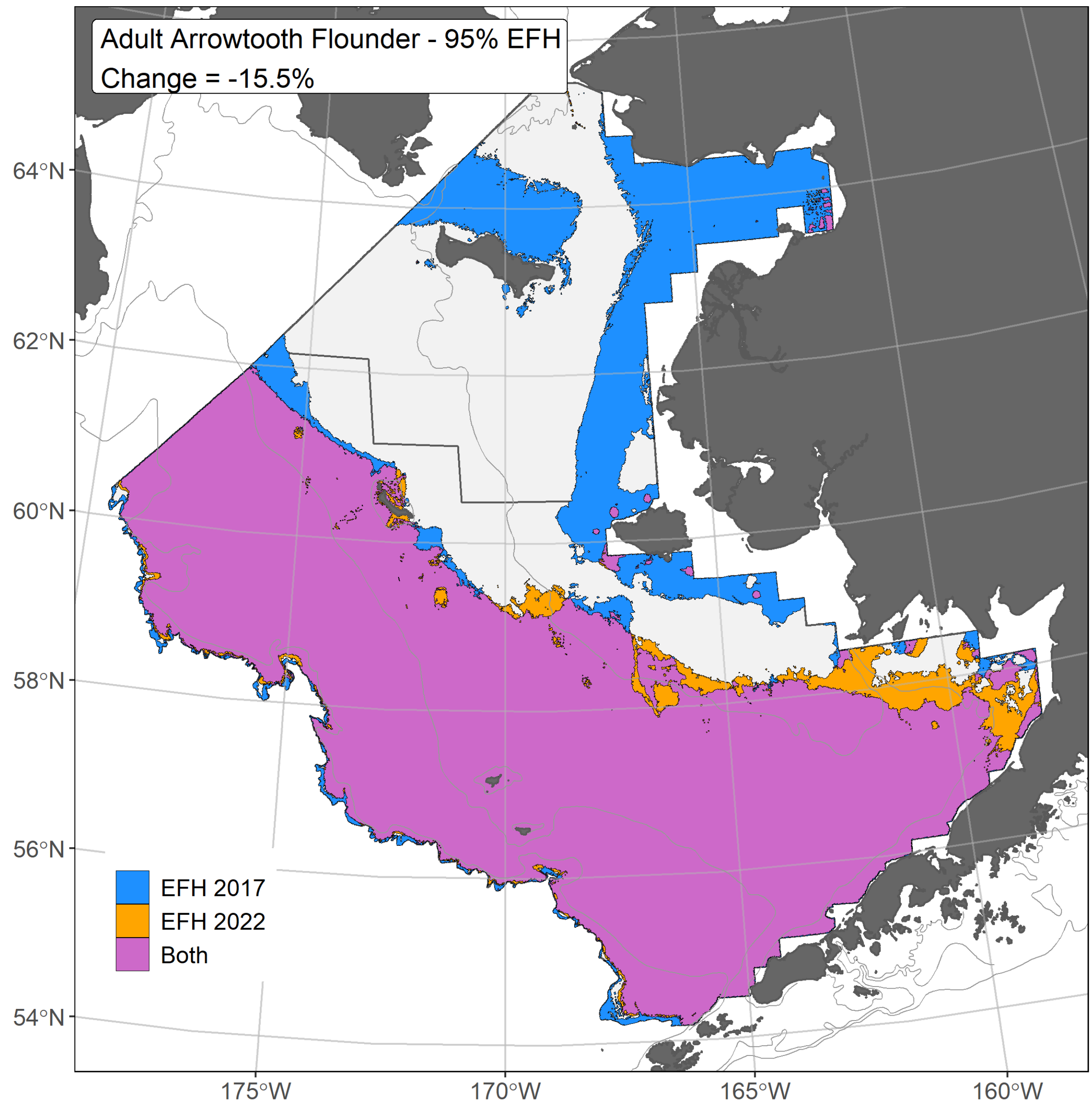

Figure 13. Change from 2017 to 2022 in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult arrowtooth flounder catches in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 2017, 2022, or both.

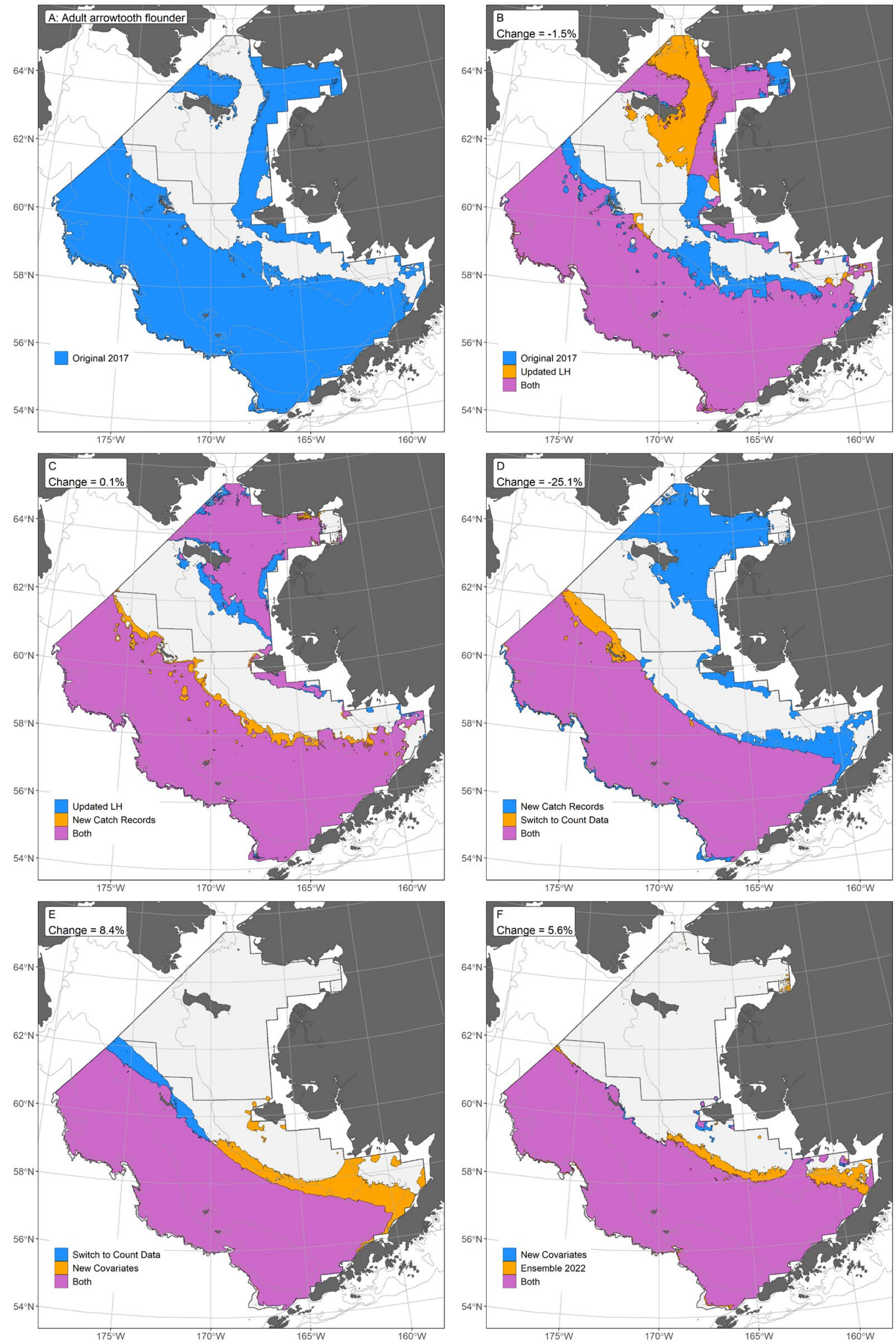

Figure 14. Change in EFH area for adult arrowtooth flounder as a result of successive alterations to the SDM approach to mapping EFH for the 2022 EFH 5-year Review. Panel A shows the 2017 EFH map. Panel B shows the change resulting from the addition of new life history information. Panel C shows the addition of new catch records between 2015 and 2019. Panel D shows the results of changes to the modelling process, including using a count data model. Panel E shows the addition of new habitat covariates. Panel F shows the 2022 EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 50 m, 100 m, and 200 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 13.

3.3.2.3 Golden king crab in the Aleutian Islands

Golden king crab (*Lithodes aequispinus*, GKC) are found from the coast of British Columbia across the North Pacific to Japan. GKC are typically found in deep water (>300 m; Somerton and Otto 1981) and often prefer high-relief rocky or coral habitats. These characteristics make it more difficult to harvest with trawl gear, and prior to the mid-1980s, the fishery for GKC was limited. However, declines in other king crab species have resulted in increased interest in this species and prompted advances in its management (Olson et al. 2018). The reproductive cycle is thought to last approximately 24 months and at any time of year, ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Eggs are large compared to other king crab species and are carried by the females for an extended period before hatching. Larvae do not appear to remain at depth and owing to the large yolk reserves, can develop into juveniles without additional feeding (Shirley and Zhou 1997). Long molting cycles also contribute to difficulty in assigning ages to this species. These life history complexities and the lack of a fishery independent crab survey have made GKC populations difficult to assess using standard age-based stock assessment tools (Siddeek et al. 2019). GKC life stages caught in RACE-GAP summer bottom trawl surveys are combined in an SDM ensemble for mapping EFH in the Aleutian Islands.

GKC from the RACE-GAP summer survey were distributed in the Aleutian Islands from 169° W across the archipelago (Figure 15). Catches occurred primarily along the continental slope and were most common around Seguam Pass. Five models were initially fitted to observed abundance. The GAM_P was selected over the GAM_{nb} by skill testing with RMSE, so only the GAM_P was included in the ensemble (Table 10). The final ensemble contained four models with approximately equal weights and achieved a good fit to the data (Table 10). The ensemble was good at predicting relatively high or low density areas (ρ = 0.56), discriminating locations where this species was likely to be present (AUC = 0.89), and was able to account for a good portion of the ensemble deviance (PDE = 0.48). Bottom depth, bottom current, and geographic location were the most important covariates and accounted for 55.9 % of the deviance explained by the ensemble, but other covariates such as maximum tidal current, bottom temperature, and slope aspect were also important (Table 11). In general, high GKC abundance was predicted at deeper depths, in northeasterly bottom current, with strong tidal movement, lower temperatures, and rocky terrain (Figure 16). Predicted abundance was highest in the area between Atka and Unalaska Islands, with pockets of high density predicted further to the west. The CV of abundance predictions was higher in areas where predicted abundance was also higher, which reflects uncertainty in the numbers caught in higher abundance areas (Figure 15). Encounter probability was higher in most of the passes throughout the island chain, which is consistent with the modelled preference for deep water and stronger currents (Figure 17).

Based on RACE-GAP summer bottom trawl data (1991–2019), the habitat-related predicted abundance was translated into EFH area and additional subareas (Figure 18). The EFH area of GKC in the AI encompassed most of the survey area along the continental slope at depths greater than 300 m. EFH hot spots occurred in Seguam Pass, Amchitka Pass, and Buldir Strait. The ensemble predicting GKC abundance and forming the basis for describing its EFH had good performance across multiple metrics.

Table 10. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for GKC: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; and GAM_{nb} = standard negative-binomial GAM. Ensemble performance (ρ = Spearman's rank correlation coefficient), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE) were generated from 10-fold cross-validation. The presence of "--" in a field indicates that this value was not calculated because the corresponding model was eliminated from the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	6.95	0.23	0.55	0.89	0.17	40,900
paGAM	6.60	0.26	0.56	0.89	0.25	47,400
hGAM	6.64	0.26	0.53	0.89	0.26	49,500
GAM_P	6.69	0.25	0.51	0.85	0.23	53,100
GAM_{nb}	6.75	0	--	--	--	--
ensemble	6.13	1	0.56	0.88	0.48	51,400

* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.

Table 11. Covariates retained in the GKC species distribution model (SDM) final ensemble, the percent contribution to the total deviance explained by each, and the cumulative percent deviance: SD = standard deviation, and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	29.5	29.5
current	14.8	44.3
geographic location	11.5	55.9
tidal maximum	7.2	63.1
bottom temperature	6.2	69.3
aspect northness	5.0	74.3
current SD	4.6	78.9
rockiness	4.6	83.5
aspect eastness	4.1	87.6
coral presence	3.3	90.9
sponge presence	3.1	94.0
slope	2.3	96.3
curvature	2.2	98.5
BPI	1.5	100.0
pennatulacean presence	0.0	100.0

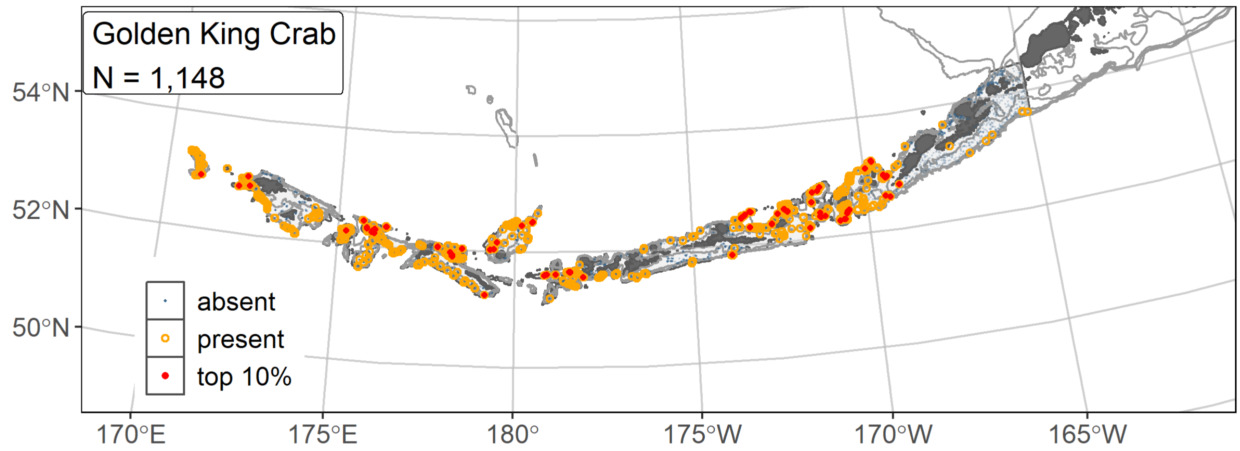

Figure 15. Distribution of GKC catches (N = 1,148) in 1991–2019 AFSC RACE-GAP summer bottom trawl surveys of the Aleutian Islands with the 100 m, 300 m, and 500 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and small blue dots indicate absence.

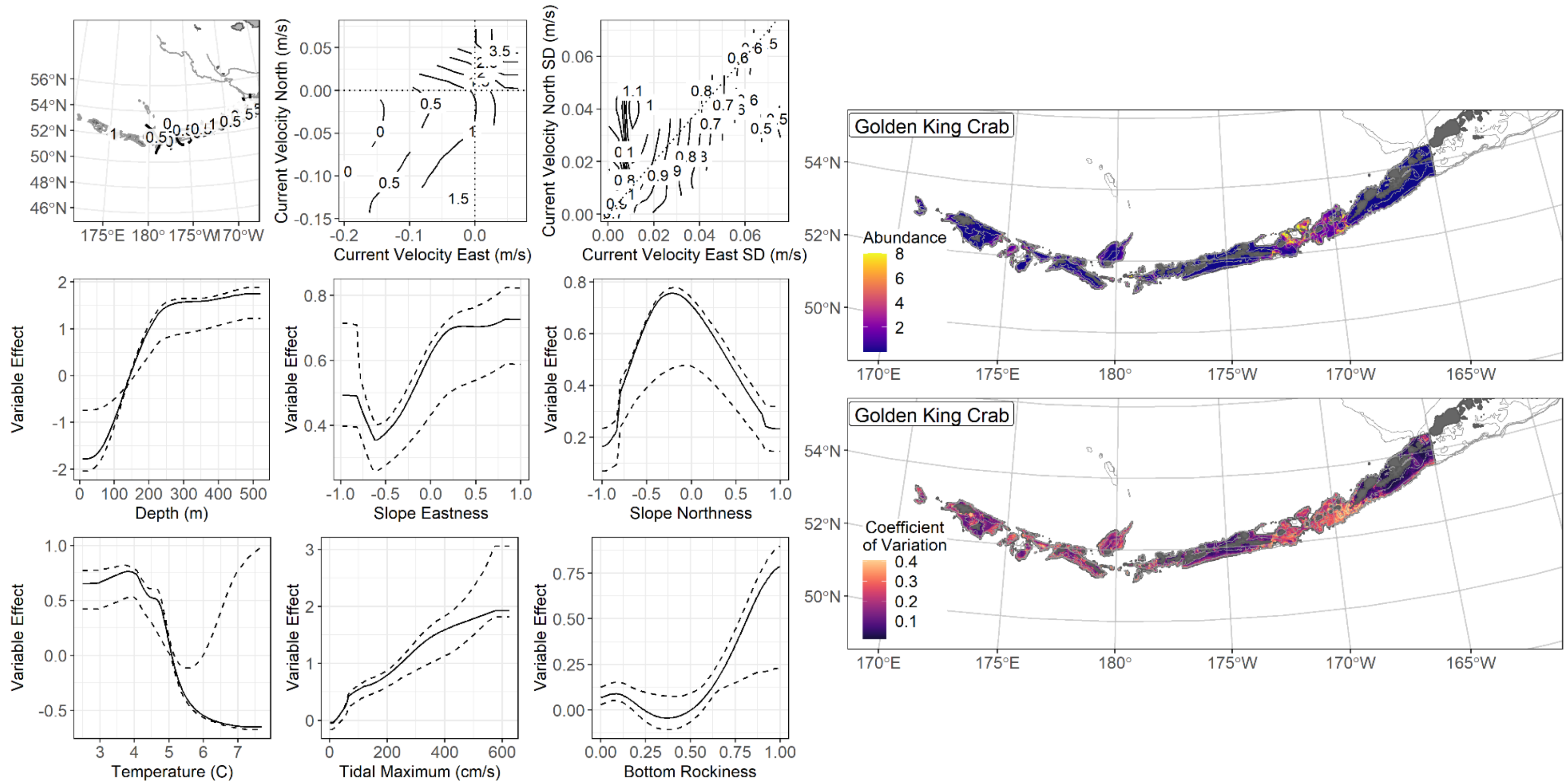

Figure 16. The top nine covariate effects (left panel) on ensemble-predicted GKC numerical abundance across the Aleutian Islands (upper right panel) alongside the coefficient of variation (CV) of the ensemble predictions (lower right panel).

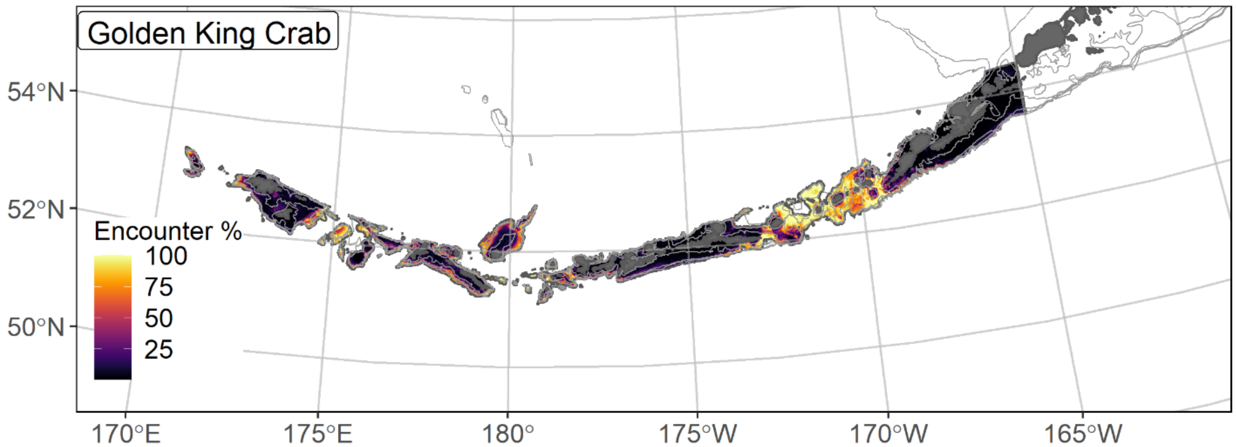

Figure 17. Encounter probability of GKC from AFSC RACE-GAP summer bottom trawl surveys (1991–2019) of the Aleutian Islands with the 100 m, 300 m, and 500 m isobaths indicated.

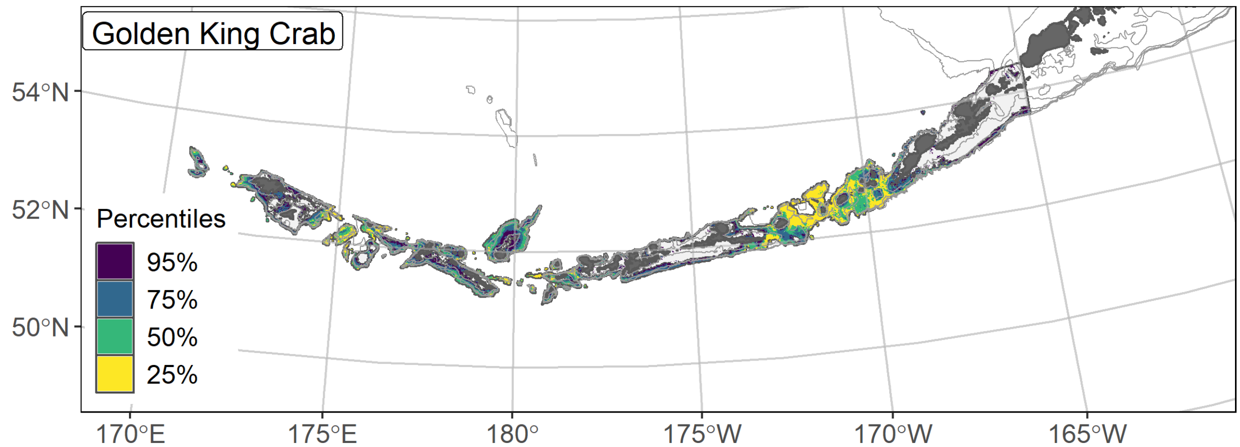

Figure 18. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from a habitat-based ensemble fitted to GKC distribution and abundance in AFSC RACE-GAP summer bottom trawl surveys (1991–2019) with 100 m, 300 m, and 500 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area) of habitat-related, ensemble-predicted numerical abundance.

3.3.2.4 Bridging the 2017 and 2022 EFH designations for golden king crab in the Aleutian Islands

The new ensemble produced for the 2022 5-year Review showed improved performance relative to the 2017 SDM (Table 12). The scores for RMSE, ρ, and AUC were nearly identical, but the 2022 ensemble showed improvement in terms of deviance explained (PDE). These metrics suggest that the new 2022 ensemble is a marginal improvement over the 2017 SDM.

The changes implemented during the 2022 EFH 5-year Review resulted in an increase of 94.8% in GKC EFH area from 26,400 km^2 modeled from an hGAM in 2017 (i.e, an SDM known to produce highly constrained area predictions) to 51,400 km^2 modeled with an ensemble in 2022 (Figure 19). The increase in area was attributable to an extension of EFH into shallower areas (50–200 m). GKC have been found in shallower water on RACE-GAP bottom trawl survey catches (Figure 15), and the 2022 EFH map corresponded well to the observed spatial distribution of trawl catches for this species. By comparison, the 2017 EFH map emphasized deeper areas (>200 m).

Refinements to our modeling approach altered GKC EFH relative to the 2017 areal extent (Figure 20). Panel A shows the original EFH map for GKC produced during the 2017 EFH 5-year Review. This species was modeled with an hGAM as a single life stage that combined all specimens and there were no changes to the life history information in 2022. In panel B, the addition of 5 more years of bottom trawl survey data, including 192 new catches of GKC, had little effect on the EFH area. In panel C, shifting to the prediction of numerical abundance as the response variable and updating the EFH mapping approach based on the 2022 ensemble methods resulted in a 90% increase in EFH areal extent. This step added many shallower places to the EFH area including locations near Samalga Pass, Petrel Bank, the Rat Islands, and Attu Island. The change in EFH mapping approach from 2017 to 2022 was a factor in the large increase in the predicted EFH area. Specifically, 2017 methods mapped EFH as 95% of all locations with positive CPUE and above 28% encounter probability, whereas EFH mapped based on the 2022 ensemble methods is 95% of all locations with greater than 5% encounter probability. In panel D, the addition of new terrain and bottom current covariates caused minimal changes. Similarly, in panel E, the creation of the ensemble from four SDMs produced minor changes in the EFH area.

Table 12. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2022 5-year Reviews of AI GKC. The metrics presented are Spearman's rank correlation coefficient (*ρ*), root-mean-square-error (RMSE), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2022. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM Method	N	RMSE	*ρ*	AUC	PDE	EFH Area	Core EFH Area	% Change in Area
2017	$hGAM_{CPUE}$	908	6.50	0.57	0.88	-0.29	26,400	13,900	
2022	Ensemble	1148	6.13	0.56	0.89	0.48	51,400	27,100	94.8%

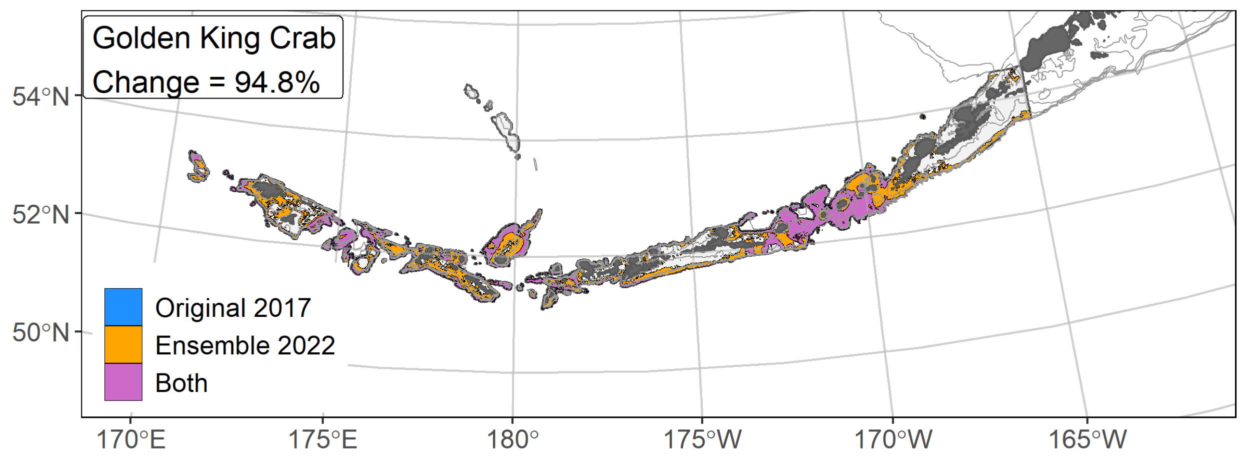

Figure 19. Change from 2017 to 2022 in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from GKC catches in AFSC RACE-GAP summer bottom trawl surveys (1991–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 217, 2022, or both.

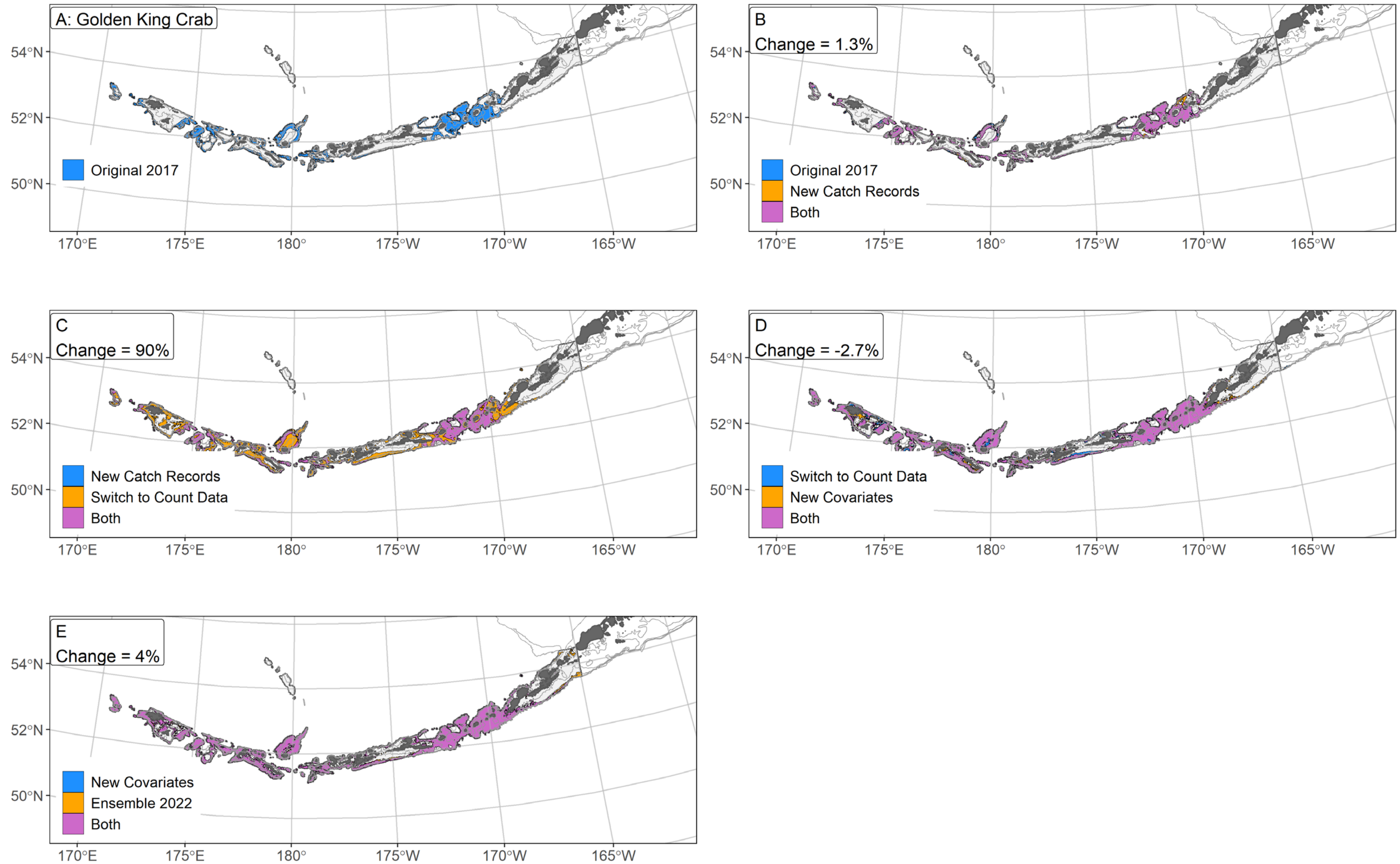

Figure 20. Change in EFH area for GKC as a result of successive alterations to the SDM process during the 2022 cycle. Panel A shows the 2017 EFH map. Panel B shows the addition of new catch records between 2015 and 2019. Panel C shows the results of changes to the modelling process, including using a count data model. Panel D shows the addition of new habitat covariates. Panel E shows the 2022 EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 50 m, 100 m, and 200 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 19.

3.3.2.5 Pacific cod adults in the Gulf of Alaska

Pacific cod (*Gadus macrocephalus*) occur from the shoreline to 500 m depth throughout the RACE-GAP study area and support important multi-gear commercial fisheries in the GOA and BSAI (Barbeaux et al. 2020, Spies et al. 2020, Thompson et al. 2020). Pacific cod form aggregations during peak spawning season (Neidetcher et al. 2014) and lay demersal, adhesive eggs with a narrow thermal window for successful incubation (3–6°C). After hatching, pelagic larvae move downward in the water column as they grow and settle as early juveniles (40–150 mm FL; Doyle et al. 2019, Laurel et al. 2009), residing in nearshore nursery habitats (< 20 m depth) until undergoing ontogenetic migration to deeper depths (Abookire et al. 2007, Laurel et al. 2007, Pirtle et al. 2019). Length based life stage breaks distinguish between subadults (151–503 mm FL; Laurel et al. 2009) and adults (> 503 mm FL; Stark 2007). Pacific cod growth rates are affected by water temperatures. Laboratory studies demonstrate that Pacific cod can grow two to three times faster than other boreal and Arctic gadids over a range of temperatures, yet their populations are vulnerable to the effects of marine heat waves (Laurel et al. 2016, Barbeaux et al. 2020).

Adult Pacific cod (N = 4,476) were common and widely distributed across the GOA continental shelf throughout the survey area with most concentrations of high abundance catches south of the Kenai Peninsula and west (1993–2019; Figure 21). The five constituent SDMs to predict numerical abundance of adult Pacific cod in the GOA converged (Table 13); the GAM_P was eliminated by skill testing. The remaining four SDMs were equally weighted in the final ensemble, which attained a good fit to the observed adult Pacific cod distribution and abundance data. The ensemble was good at predicting catches ($\rho = 0.47$) and at discriminating presence-absence (AUC = 0.75), and fair at explaining deviance (PDE = 0.25). Bottom depth, geographic location, and bottom temperature accounted for 78.1% of the deviance explained by the ensemble (Table 14). Adult Pacific cod abundance predicted from the ensemble was highest west of the Kenai Peninsula (Figure 22). The CV of ensemble predictions was high in the glacial troughs, along the continental slope, and in the eastern GOA. The probability of encountering adult Pacific cod was high across the continental shelf and low along the continental slope and glacial troughs in the eastern GOA (Figure 23).

Habitat-related predictions of adult Pacific cod distribution and abundance from RACE-GAP bottom trawl surveys (1993–2019) was mapped as EFH areas and subareas (Figure 24). The EFH area for adult Pacific cod extended from southeast Alaska to the western GOA. EFH hot spots were most prominent on the continental shelf west of the Kenai Peninsula.

Table 13. Constituent species distribution models (SDMs) used to construct the ensemble predicting Essential Fish Habitat (EFH) for adult Pacific cod: MaxEnt = Maximum entropy; paGAM = presence-absence generalized additive model; hGAM = zero-adjusted Poisson hurdle GAM; GAM_P = standard Poisson GAM; GAM_{nb} = standard negative-binomial GAM; RMSE = root mean square error; ρ (*rho*) = Spearman's rank correlation coefficient; AUC = area under the receiver operating characteristic curve; and PDE = Poisson deviance explained *. The "–" indicates that this model was not included in the final ensemble.

Models	RMSE	Relative Weight	ρ	AUC	PDE	EFH area (km^2)
MaxEnt	71.6	0.25	0.45	0.75	0.05	272,800
paGAM	71.3	0.25	0.49	0.77	0.09	261,900
hGAM	71.1	0.25	0.40	0.77	0.18	257,500
GAM_P	71.1	–	–	–	–	–
GAM_{nb}	70.9	0.25	0.41	0.72	0.18	258,600
ensemble	70.2	1	0.47	0.75	0.25	264,700

* Refer to the Species Distribution Model Performance Metrics subsection within the Statistical Modeling section of the Methods for detailed descriptions of individual model performance metrics.

Table 14. Covariates retained in the species distribution model (SDM) final ensemble for adult Pacific cod with the percent contribution of each covariate to the deviance explained by the SDMs and the cumulative deviance explained: SD = standard deviation and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	53.1	53.1
geographic location	15.6	68.7
bottom temperature	9.4	78.1
tidal maximum	5.7	83.7
current	3.3	87.0
BPI	2.9	89.9
aspect eastness	2.6	92.5
current SD	2.1	94.6
slope	1.8	96.4
rockiness	1.3	97.7
sponge presence	1.1	98.8
aspect northness	0.9	99.7
coral presence	0.1	99.8
pennatulacean presence	0.1	99.9
curvature	0.1	100.0

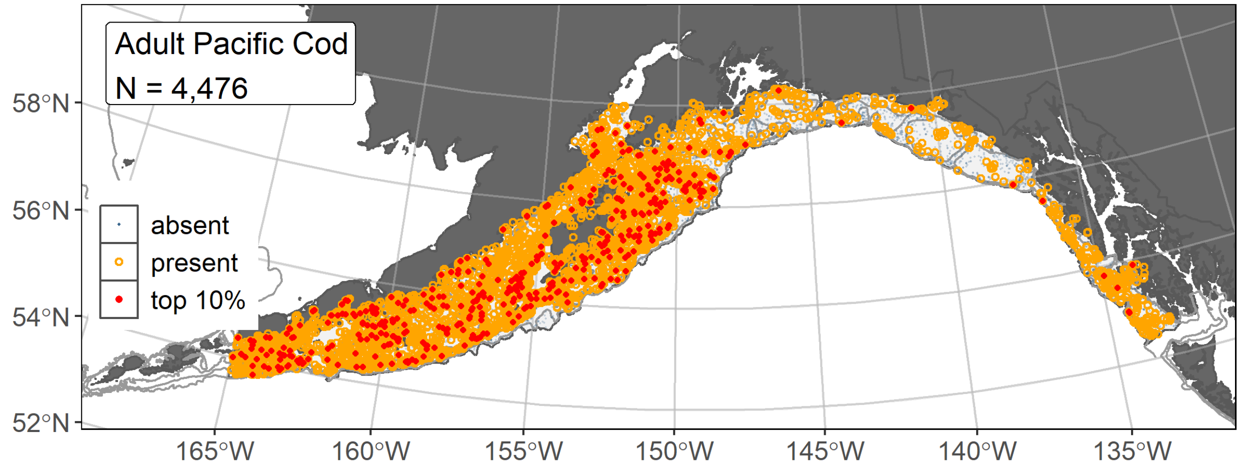

Figure 21. Distribution of adult Pacific cod catches (N = 4,476) in 1993–2019 AFSC RACE-GAP summer bottom trawl surveys of the Gulf of Alaska with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

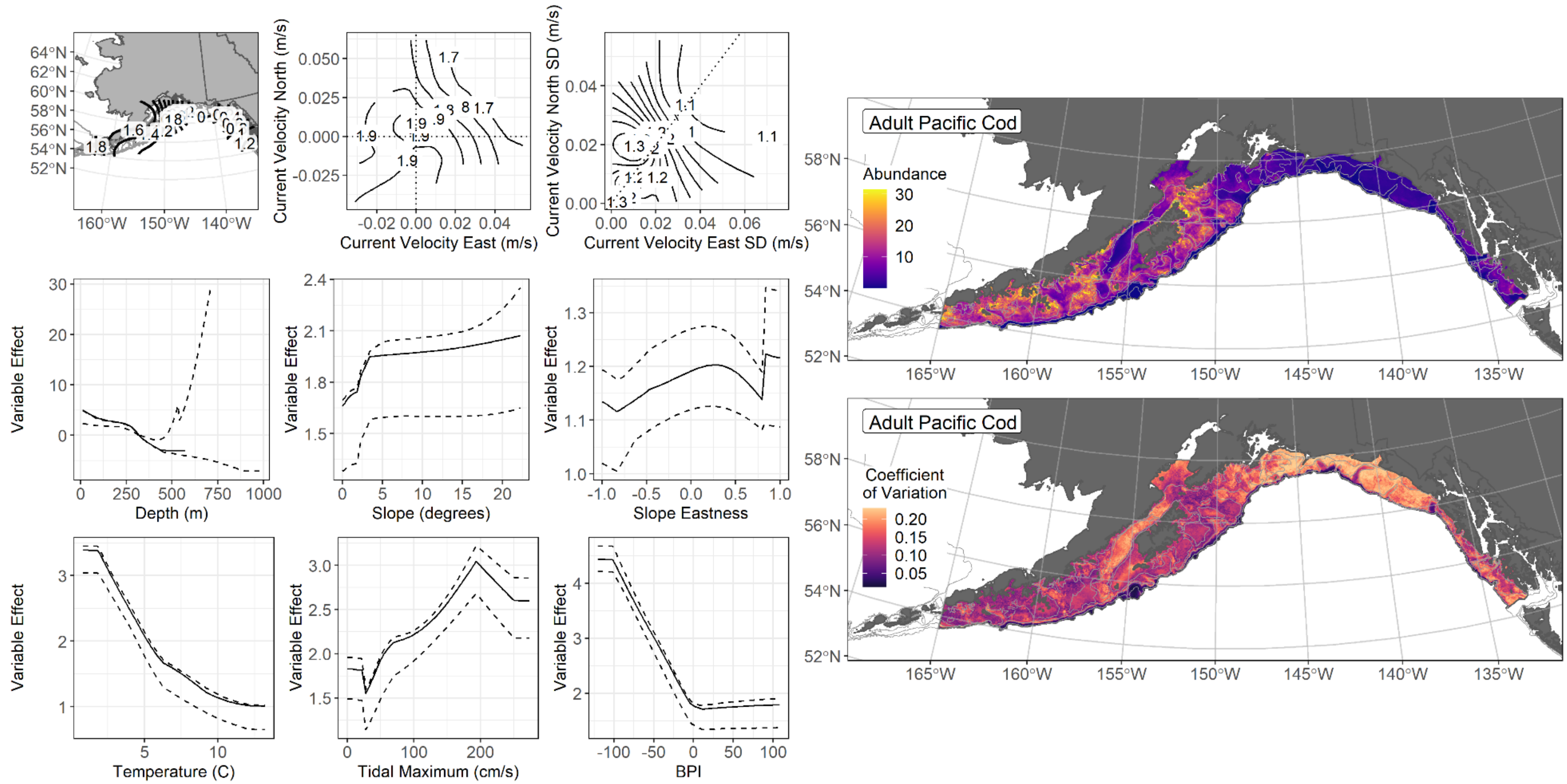

Figure 22. The top nine covariate effects (left panel) on ensemble-predicted adult Pacific cod numerical abundance across the Gulf of Alaska (upper right panel) along with the coefficient of variation (CV) of the ensemble predictions (lower right panel).

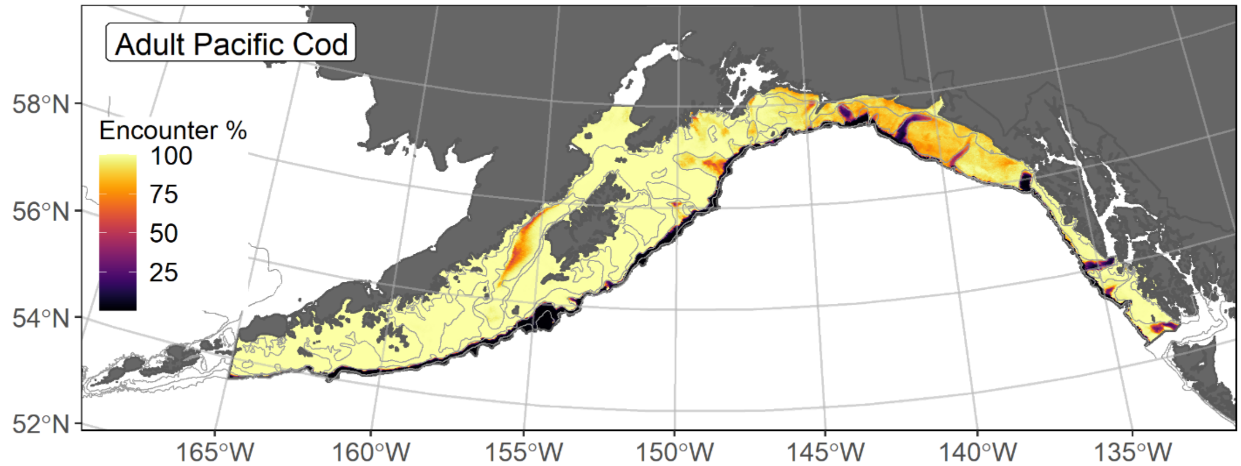

Figure 23. Encounter probability of adult Pacific cod from AFSC RACE-GAP summer bottom trawl surveys (1993–2019) of the Gulf of Alaska with the 100 m, 200 m, and 700 m isobaths indicated.

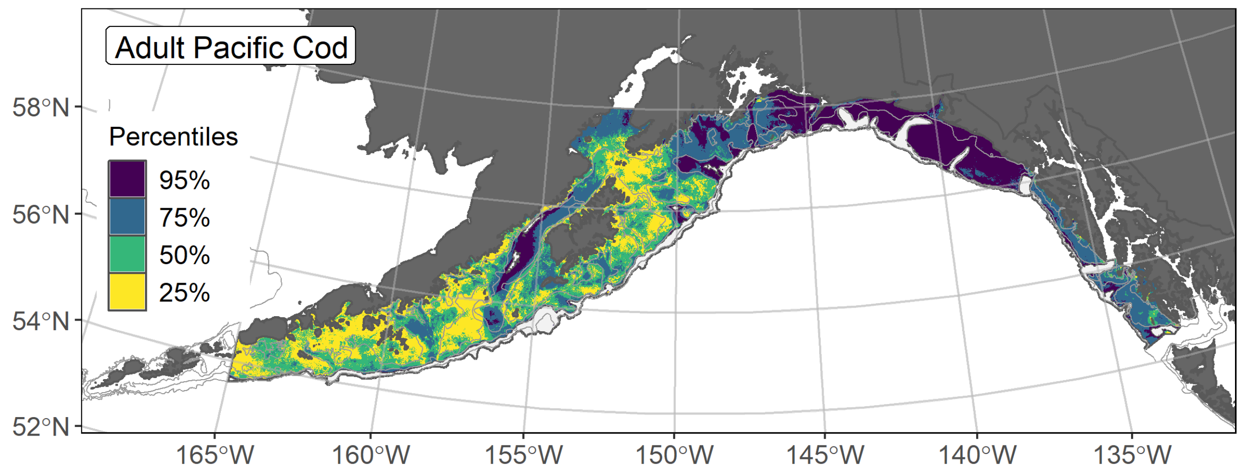

Figure 24. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat (defined as model estimated encounter probabilities greater than 5%) from an SDM ensemble fitted to adult Pacific cod distribution and abundance in AFSC RACE-GAP GOA summer bottom trawl surveys (1993–2019) with 100 m, 200 m, and 700 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

3.3.2.6 Bridging the 2017 and 2022 EFH designations for adult Pacific cod in the Gulf of Alaska

The new ensemble produced for the 2022 EFH 5-year Review showed improved performance relative to the 2017 SDM (Table 16). The scores for ρ and AUC were nearly identical, but the 2022 ensemble showed improvement in terms of RMSE and deviance explained (PDE). These metrics suggest that the new 2022 ensemble is an improvement over the 2017 SDM.

The changes implemented during the 2022 EFH 5-year review resulted in a minor decrease in adult Pacific cod EFH area from 295,900 km^2 in 2017 to 264,700 km^2 in 2022; a change of -4.7% (Figure 25). The decrease in area is caused by the removal of locations in deep water along the continental slope, as well as some glacial troughs in the southeast GOA. This decrease was partially offset by the addition of continental shelf areas up to a depth of 200 m south of Yakutat Bay.

Refinements to our modeling approach altered adult Pacific cod EFH relative to the 2017 areal extent (Figure 26). Panel A shows the original EFH map for adult Pacific cod produced during the 2017 EFH 5-year Review. In Panel B, the life stage definition for adults was changed from all specimens greater than the length at first maturity (420 mm T.L.; Stark 2007) to the length at 50% maturity (503 mm T.L.; Stark 2007), and this resulted in a minor reduction in EFH area. In panel C, the addition of 5 more years of bottom trawl survey data, including 723 new catches of adult Pacific cod, had little effect on the EFH area. In panel D, shifting to the prediction of numerical abundance as the response variable and updating the EFH mapping approach based on the 2022 ensemble methods also resulted in a small reduction in EFH area in deeper areas and along the continental slope. In panel E, the addition of new terrain and bottom current covariates caused no net change in the size of the overall EFH area. Lastly, in panel F, the creation of the ensemble from four SDMs produced a minor increase in the EFH area.

Table 15. Comparison of performance metrics and area for SDM predictions and EFH areal extent from the 2017 and 2022 5-year Reviews of GOA adult Pacific cod. The metrics presented are Spearman's rank correlation coefficient (ρ), root-mean-square-error (RMSE), the area under the receiver operating characteristic (AUC), and the Poisson deviance explained (PDE). The 2017 SDM predictions were converted from 4th root CPUE to count abundance prior to calculating the performance metrics assessed in 2022. The percent change in area (km^2) is constant for the EFH area and core EFH area.

EFH Review	SDM method	N	RMSE	ρ	AUC	PDE	EFH area (km^2)	Core EFH area (km^2)	% Change in area
2017	GAM_{CPUE}	3,615	97.9	0.48	0.76	-0.36	295,900	155,700	
2022	Ensemble	4,476	70.2	0.47	0.75	0.25	264,700	139,300	-4.7%

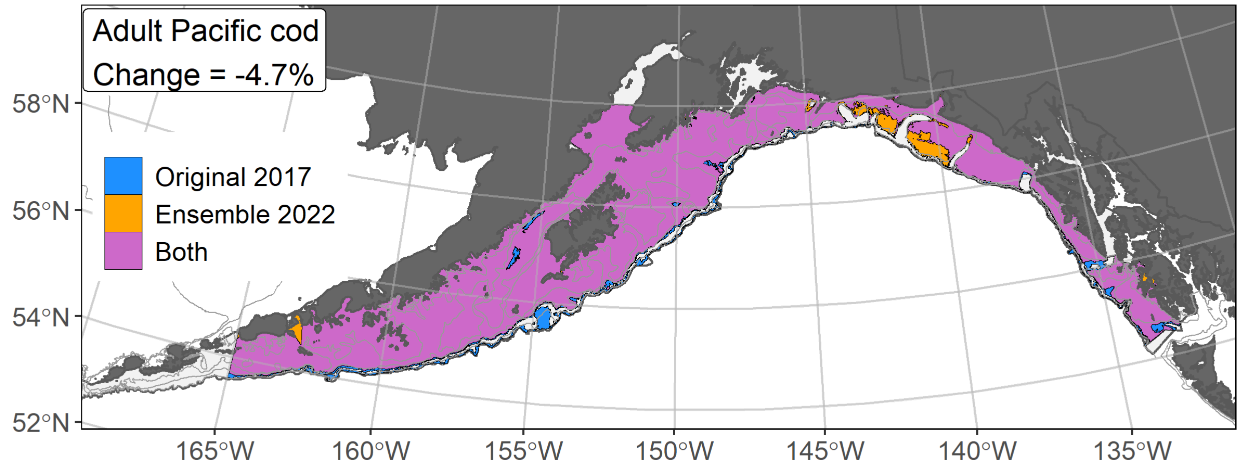

Figure 25. Change from 2017 to 2022 in essential fish habitat (EFH) area, which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult Pacific cod catches in AFSC RACE-GAP summer bottom trawl surveys (1993–2019) with 100 m, 200 m, and 700 m isobaths indicated. Colored areas represent EFH in 2017, 2022, or both.

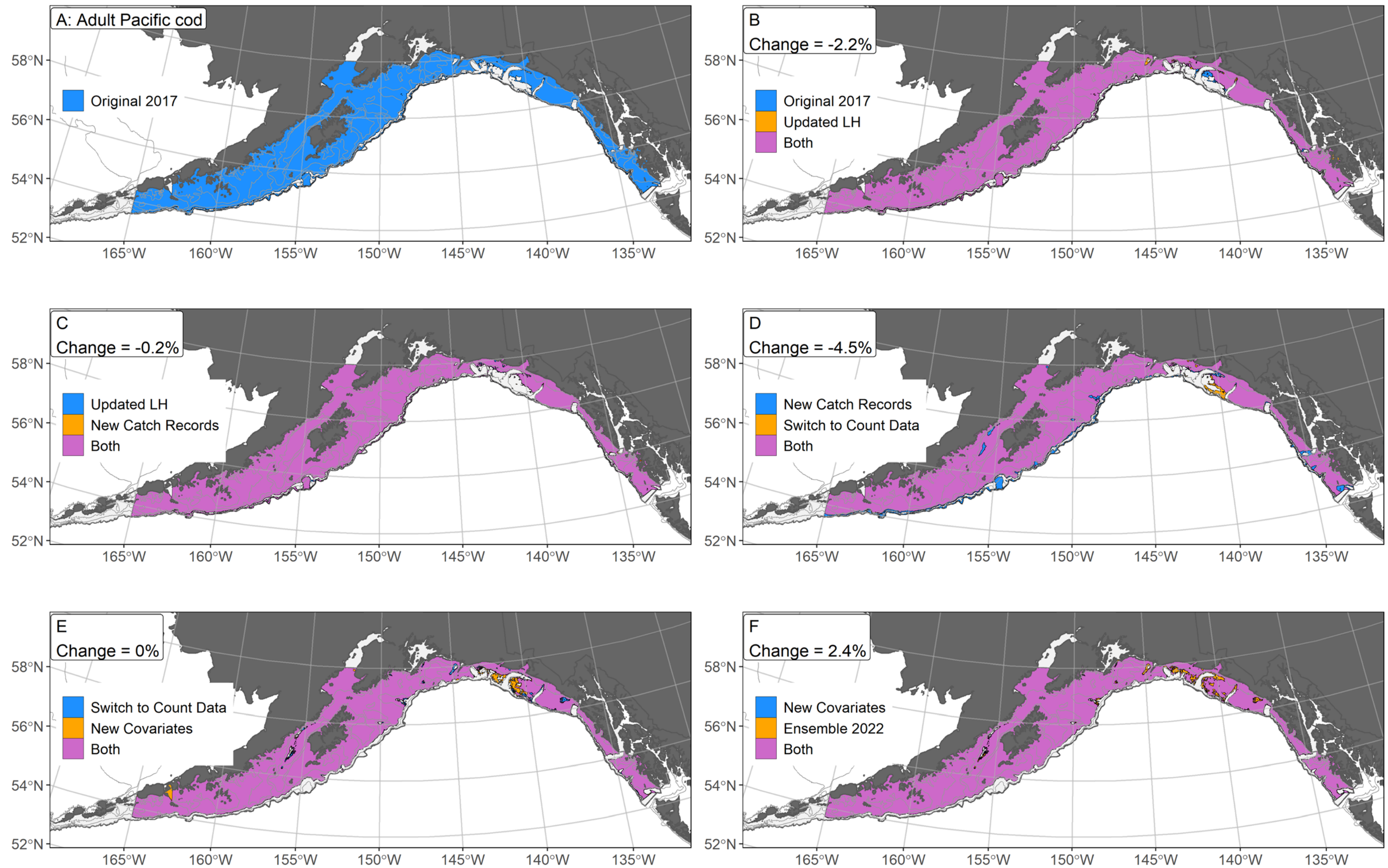

Figure 26. Change in EFH area for adult Pacific cod as a result of successive alterations to the SDM process during the 2022 EFH 5-year Review. Panel A shows the 2017 EFH map. Panel B shows the change resulting from the addition of new life history information. Panel C shows the addition of new catch records between 2015 and 2019. Panel D shows the results of changes to the modelling process, including using a count data model. Panel E shows the addition of new habitat covariates. Panel F shows the 2022 EFH map, derived from the combined predictions of four constituent SDMs in an ensemble. The 100 m, 200 m, and 700 m isobaths are indicated. The % change in area is calculated relative to the previous step, and is different from the overall change shown in Figure 25.

3.3.2.7 Pacific cod settled early juveniles in the Gulf of Alaska

Settled early juvenile Pacific cod (N = 354) caught in mixed gear-type summer surveys (1989–2019) were distributed primarily inshore throughout the GOA with some occurrences at shallower depths offshore on the continental shelf (Figure 27). Settled early juvenile Pacific cod presence records from multiple surveys were combined in a habitat-related MaxEnt model predicting suitable habitat probabilities for this life stage in the GOA. The best model had a β-multiplier of 2.5 and an AUC of 0.95 (Table 17). Bottom depth contributed the most (69.9%) to the MaxEnt model (Table 18). The highest probabilities of suitable habitat for early juvenile Pacific cod in the GOA were predicted in coastal nearshore areas and around islands throughout the GOA (Figure 28). The areas with the highest error around the MaxEnt predictions for settled early juvenile suitable habitat corresponded to the locations where high probabilities of suitable habitat were predicted.

Habitat-related predictions of settled early juvenile Pacific cod distribution from summer surveys of the GOA (mixed gear-type summer surveys (1989–2019) and RACE-GAP bottom trawl surveys (1993–2019)) was mapped as EFH areas and subareas (Figure 29). Settled early juvenile Pacific cod EFH included nearshore areas and bathymetric rises on the continental shelf most prevalent in the central and western GOA. Core EFH areas and EFH hot spots for settled early juveniles were generally associated with shallower nearshore areas and bathymetric rises. Pacific cod ontogenetic differences in depth distribution (e.g., Laurel et al. 2009, Pirtle et al. 2019) were reflected by the predicted EFH areas among life stages modeled, with the greatest difference between the early juveniles and older life stages (Figure 24).

Table 16. Maximum entropy model (MaxEnt) used to construct Essential Fish Habitat (EFH) for settled early juvenile Pacific cod: regularization multiplier (β); *k*-fold cross-validation root-mean-square-error (RMSE), area under the receiver operating characteristic curve (AUC), and areal extent of EFH (km^2).

Model	β	RMSE	AUC	EFH area (km^2)
MaxEnt	2.5	112.90	0.95	124,800

Table 17. Covariates retained in the habitat-related maximum entropy (MaxEnt) model for settled early juvenile Pacific cod with the percent contribution of each covariate to the deviance explained by the SDMs and the cumulative deviance explained: SD = standard deviation and BPI = bathymetric position index.

Covariate	% Contribution	Cumulative % Contribution
bottom depth	69.9	69.9
aspect eastness	7.4	77.3
BPI	5.9	83.2
aspect northness	5.2	88.5
rockiness	3.9	92.4
tidal maximum	3.2	95.6
curvature	2.0	97.6
bottom temperature	0.9	98.5
coral presence	0.8	99.3
sponge presence	0.7	100.0

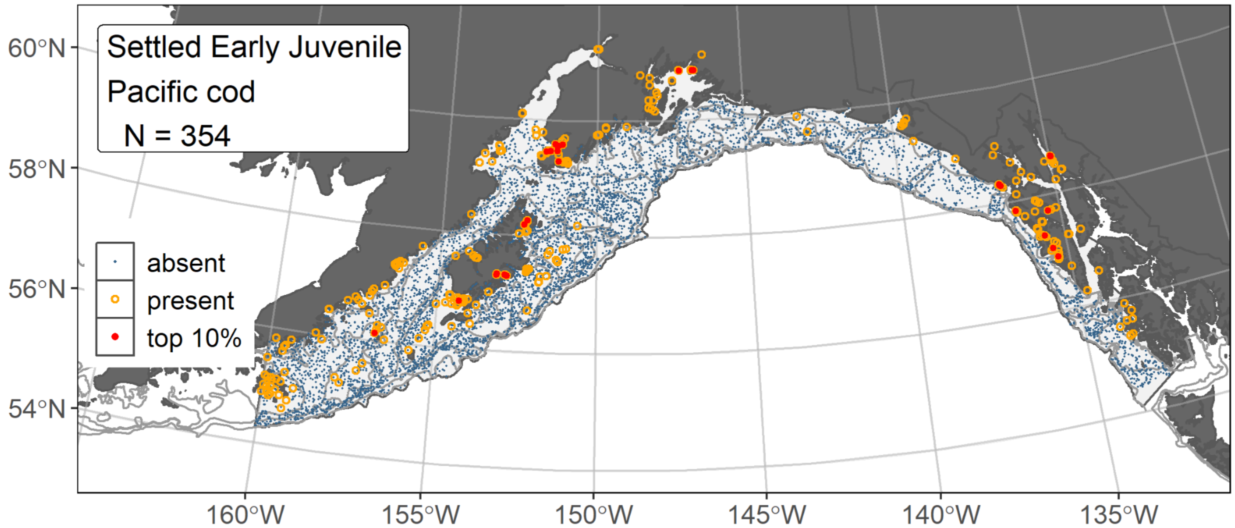

Figure 27. Distribution of settled early juvenile Pacific cod catches (N = 354) in mixed gear-type summer surveys of the Gulf of Alaska (1989–2019) with the 100 m, 200 m, and 700 m isobaths indicated; filled red circles indicate locations in top 10% of overall abundance, open orange circles indicate presence in remaining catches, and blue dots indicate stations sampled where the animals were not present.

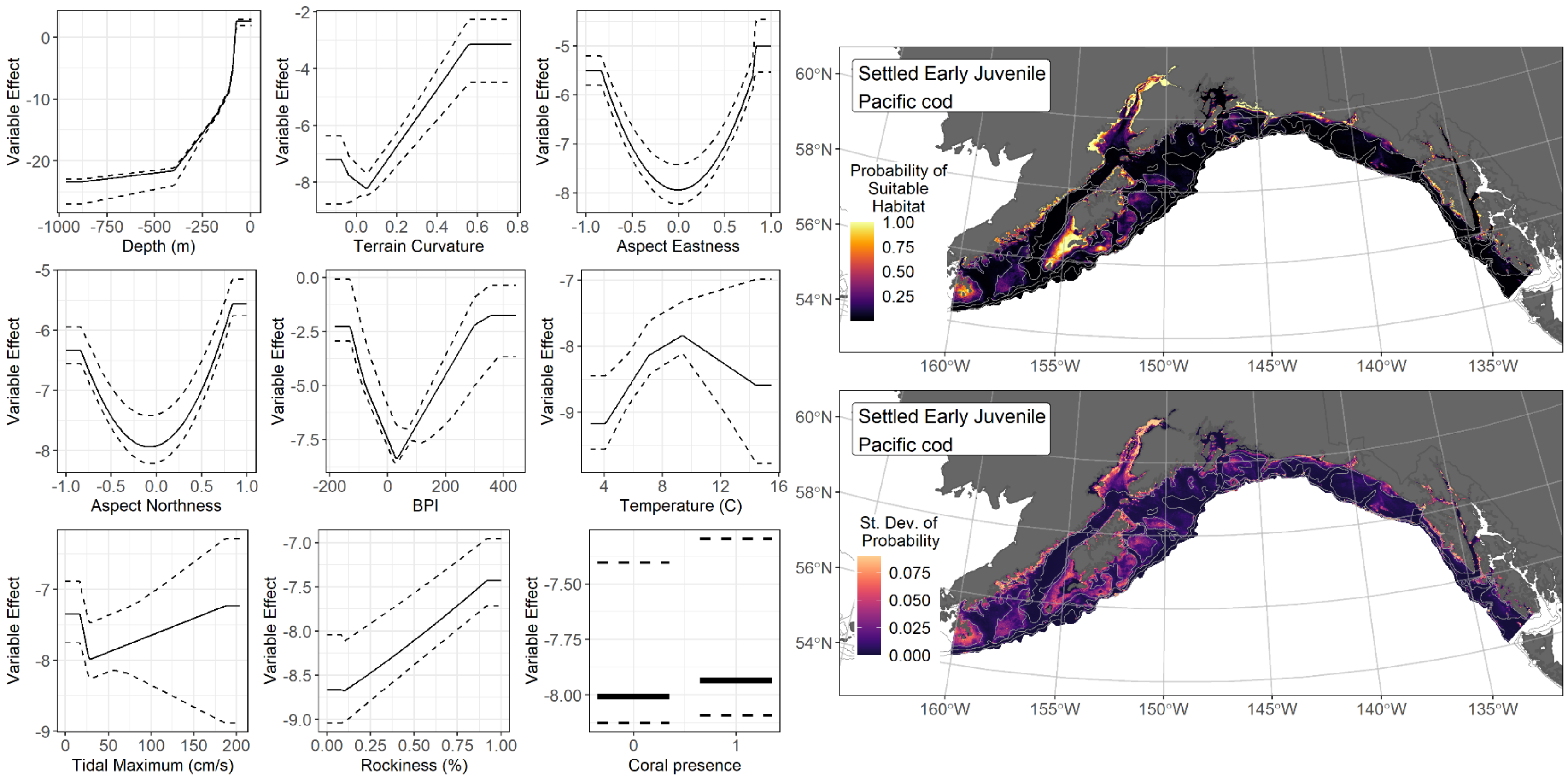

Figure 28. The top nine covariate effects (left panel) from a habitat-related SDM (MaxEnt) of settled juvenile Pacific cod probability of suitable habitat in the Gulf of Alaska (upper right panel) with the standard deviation of the probability predictions (lower right panel).

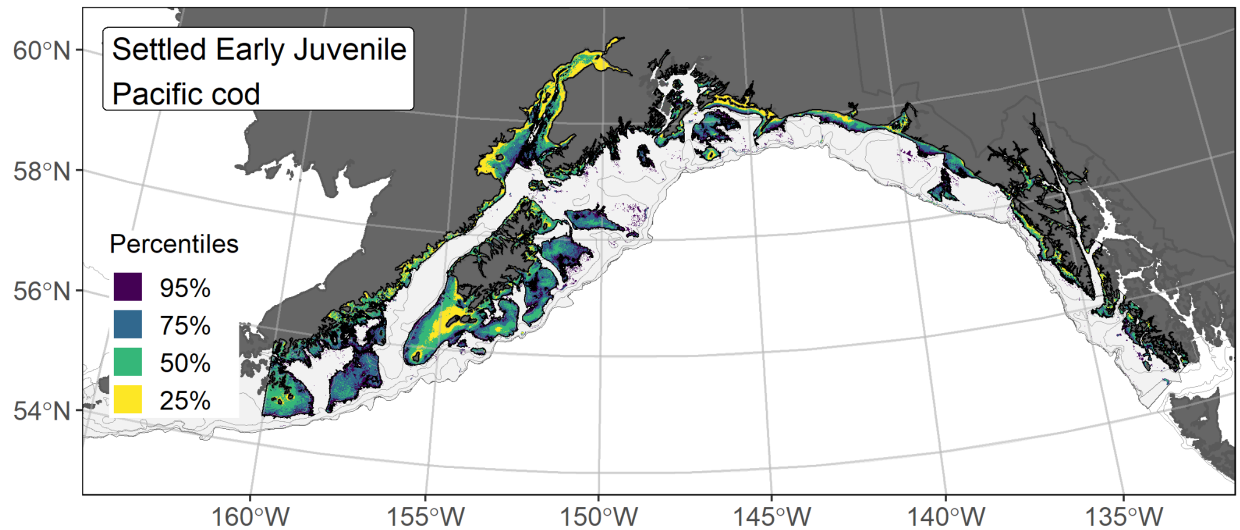

Figure 29. Essential fish habitat (EFH) is the area containing the top 95% of occupied habitat for settled early juvenile Pacific cod (defined as greater than 5% predicted probability of suitable habitat) from an SDM fitted to their distribution in Gulf of Alaska (GOA) mixed gear-type summer surveys (1989–2019) with 100 m, 200 m, and 700 m isobaths indicated; within the EFH area map are the subareas of the top 25% (EFH hot spots), top 50% (core EFH area), and top 75% (principal EFH area).

3.3.2.8 EFH Level 3 of settled early juvenile Pacific cod in the Gulf of Alaska

Laboratory reared early juvenile Pacific cod temperature-dependent growth rate is described by the following equation (Laurel et al. 2016):

$$GR = 0.2494 + 0.3216 * T + 0.0069 * T^2 - 0.0004 * T^3$$

Where *GR* is the growth rate (% body weight (g) per day (d)), and *T* is the temperature. The raster product of early juvenile Pacific cod predicted probability of suitable habitat from a MaxEnt SDM (and their temperature-dependent growth is an EFH Level 3 map of habitat-related growth potential (Figure 30). The temperature of maximum growth for early juvenile Pacific cod is 11.5°C (Laurel et al. 2016), which is within the range (2.9–17.5°C) of the CGOA ROMS 3 km summer bottom temperature covariate raster (2000–2019) applied to the SDM and to the EFH Level 3 map of habitat-related growth potential (Attachment 5 Figure 3). The bottom temperature range at settled early juvenile Pacific cod catch locations contributing to the SDM was 3.0–15.5°C (Figure 27). In the map of temperature-dependent growth, the highest growth areas occurred inshore and along the coast, as well as on the banks and bathymetric rises on the GOA continental shelf (Figure 30). The SDM of settled early juvenile stage Pacific cod suitable habitat limited areas of high predicted habitat-related growth potential (Figure 28), notably to shallower depths, suggesting that temperature was not the only driver of distribution for this life stage in the GOA. EFH subareas of core EFH area and EFH hot spots corresponded with areas of high habitat-related growth potential for settled early juvenile stage Pacific cod, which adds value in interpreting the EFH Level 1 map (Figure 29).

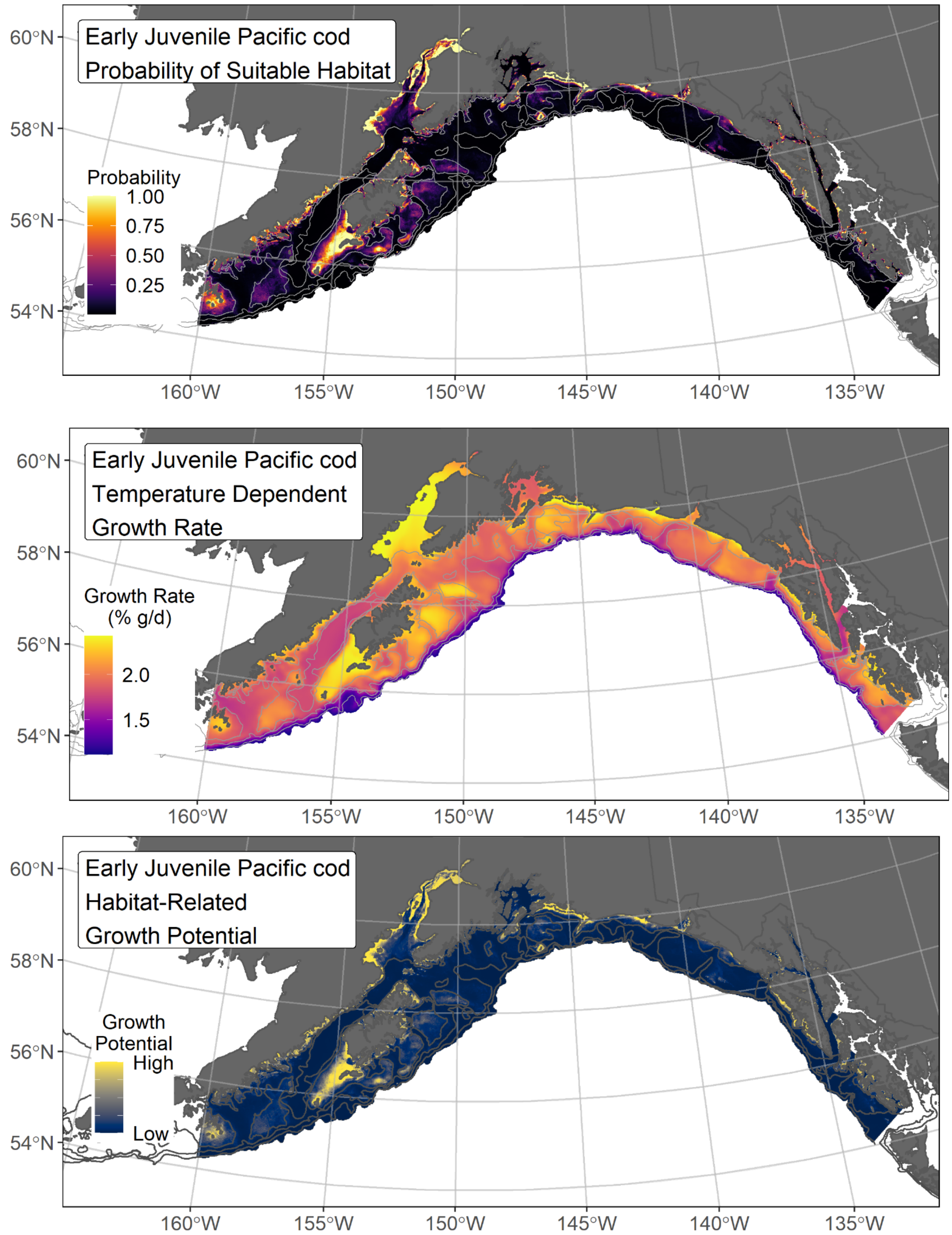

Figure 30. Settled early juvenile Pacific cod predicted probability of suitable habitat from a habitat-related SDM fitted to their distribution in Gulf of Alaska mixed gear-type summer surveys (1989–2019; top panel), temperature-dependent growth rate (GR = % body weight (g)·day-1; center panel), and EFH Level 3 map of habitat-related growth potential (bottom panel), which is the raster product of probability of suitable habitat and temperature-dependent growth rate.

3.3.3 Synthesis

3.3.3.1 Synthesis of findings regarding habitat related covariates and SDM predictions

One valuable feature of habitat-related SDMs is that they can provide insight into the environmental conditions that affect patterns of species distribution and abundance. The three most influential (highest percent contribution to the deviance explained by the SDM or ensemble) covariates for each species' life stage in the 2022 EFH 5-year Review are summarized in Table A2.1. Detailed figures and interpretations of the covariate effects are available in the corresponding chapters for each species' life stage in the three attached regional Technical Memoranda (Attachments 3-5). The covariate contribution is estimated with a jack-knife process, whereby each covariate is removed from the SDM one at a time, and the resulting decline in model performance is measured. If the deviance explained by the SDM declines by a large amount, this suggests that the covariate is important for accurate prediction. The percent contribution of the covariates is an indication of their proportional contribution to the deviance explained by the ensemble. Overall ensemble performance is indicated by the model performance metrics for assessing model fit (see performance metric details in Statistical Modeling 3.2.7). Details for the explanation and data source for each covariate can be found in Habitat Covariates 3.2.3 and Table 5.

Summarized across all the species examined, the most influential covariates for species' life stages modeled in the 2022 EFH 5-year Review were geographic location and bottom depth. One or both of these were present in the top three contributing covariates for over 90% of the ensembles. Geographic location was the combination of latitude and longitude recorded for each haul in the RACE-GAP bottom trawl surveys. Location was included to reduce the effects of spatial autocorrelation as demonstrated by Rooper et al. (2021). Bottom depth is an important determinant of fish distributions for North Pacific species (e.g., Laman et al. 2018, Pirtle et al. 2019) and in other regions globally (e.g., Macpherson and Duarte 1991). Bottom currents and bottom temperature were less influential, but each appeared in the top three for approximately 25% of the SDMs and ensembles. Tidal maximum, BPI, *phi*, rockiness, and sponge presence were occasionally top contributors, and appeared in the top three in approximately 5–15% of SDMs and ensembles. Other covariates such as terrain aspect, terrain curvature, slope, coral presence, and pennatulacean presence were only rarely included in the top three covariates. The most influential covariates also varied by region, though location and bottom depth are influential in most SDMs and ensembles across all three regions. In the AI, bottom currents were relatively more influential and bottom temperature was relatively less influential. In the Bering Sea, temperature was more influential and tidal maximum was less influential. In the GOA, sponge presence and BPI were relatively more influential than in other regions.

3.3.3.2 Comparison of 2017 and 2022 SDM performance and EFH areas

Model performance and EFH area were summarized and compared (2017 single SDM compared to 2022 ensemble) between the SDMs and EFH maps of the 2017 and 2022 EFH 5-year Reviews (Table A3.2). The SDM selected in 2017 had a strong influence on the resulting performance metrics and EFH areas. The MaxEnt models fitted from the *dismo* package used in the 2017 EFH 5-year Review have a different design and are not directly comparable to the MaxEnt models fitted from the *maxnet* package used for the 2022 EFH 5-year Review; only AUC can be computed for comparison between these cases. The 2017 EFH 5-year Review did not include SDMs for settled early juveniles so no comparison between years was possible. Neither did we compare species modeled where life stages were combined in 2017 (2022) with the same species modeled where those life stages were distinct in 2022 (2017); these species are absent from Table A3.2. However, the SDM and ensemble results by region for each species' life stage modeled in 2022 are in Table A2.2 along with the number of positive catches, RMSE, performance metrics (ρ, AUC, and PDE), EFH area, and the EFH subarea "core EFH area."

In the majority of cases, the performance metrics from the 2022 SDM ensembles demonstrated clear improvements over those from 2017. The 2022 ensembles showed improvement in RMSE in 88%

of models, improvement in Spearman's correlation (ρ) in 69% of models, improvement in area under the receiver operating characteristic curve (AUC) in 52% of models, and improvement in Poisson deviance explained (PDE) in 99% of models. In other cases, where clear improvement was not observed, the difference between the models was usually small, and in no instance was a decline observed across all metrics. When comparing SDMs from different years, it is important to consider that additional changes to the data, such as updated life history information, may have a large effect on model predictions. Therefore, the results (Table A2.1 and Table A3.2) should be considered in context with the more detailed results descriptions reported in each species' life stage in the three regional Technical Memoranda from this study (Attachments 3-5). Approximately 25% of ensembles in the present work predicted EFH areas larger by 100% or more; in almost all of these cases the 2017 SDM was the restrictive hGAM. Approximately 18% of ensembles resulted in EFH areas that were smaller by at least 50%; in all cases the 2017 SDM was a MaxEnt model.

3.3.3.3 Summary of 2022 SDM performance with additional metrics

The 2022 EFH 5-year Review used four metrics to assess the predictive skill of SDM ensembles. The RMSE is a measure of the variance in predictions relative to the observed data, and was used to weight the constituent SDMs for each species life stage. The RMSE is useful for comparing different models, though it does not provide information about fit on its own. Spearman's rank order correlation (ρ) is a measure of whether an SDM predicts the relative ordering of high or low values in the data, and is used to assess model fit. Area under the receiver operating characteristic curve (AUC) is a measure of discrimination ability and is used to assess the ability of a model to correctly predict presence or absence. The Poisson deviance explained (PDE) is a measure of fit that adjusts for the non-normal errors expected from count data and is used to assess the ability of a model to predict the observed abundance. See the Statistical Modeling section of the Methods in this document for additional details.

The four model performance metrics selected in this project and described above are only a small sample of the total number of statistical measures available for assessing model fit. Five additional metrics investigated to describe ensemble performance are presented in Appendix 4 Table A4.1. These provide additional nuance when interpreting the validity and fit of the ensembles. The first of these is prevalence (Prev.), the number of positive catches divided by the total number of valid hauls for that species. This metric provides further information about the relative commonness or scarcity of a species in the RACE-GAP bottom trawl surveys. The Pearson correlation (r) is a commonly used statistic that measures the degree to which model predictions match observed data. It was not used in the 2022 EFH 5-year Review because it assumes that the data follow a normal distribution; count data modeled here follow a Poisson distribution. The Pearson correlation can take on values between negative one and one; higher absolute values indicate a better fit. The Precision-Recall area under the receiver operating characteristic curve (PR-AUC) is a variation of the AUC that focuses on predictive skill for presence locations. Whereas AUC measures the rate of true positives compared to the rate of false positives, PR-AUC measures the degree of precision (true positives/predicted positives) compared to recall (true positive/observed positives). PR-AUC values range from zero to one, with higher values indicating better performance. The F_1 score (F_1),

$$F_1 = 2 * \frac{precision * recall}{precision + recall},$$

is similar to PR-AUC in that it is a measure of classification skill for presence or absence data with a focus on presence locations. The F_1 score also has a value between zero and one and is typically similar to the PR-AUC. Both PR-AUC and F_1 scores were requested by the SSC at the October 2021 meeting (Table A1.1) and are reported here. The accuracy (Acc.) is the number of correct predictions divided by the total number of observations, and provides an easier to interpret metric that focuses equally on presence and absence in the data.

3.4 Conclusions

The completion of this project advancing and re-describing EFH for North Pacific groundfish and crab species within NPFMC FMPs meets the requirements of the EFH regulations and satisfies specific objectives of the Alaska EFH Research Plan. The MSA requires NMFS and the Councils to describe and identify EFH for managed species in fishery management plans (FMPs). Federal regulations implementing the MSA require the Councils and NMFS to periodically review (at least every 5 years) the EFH components, FMPs and, potentially, to revise or amend these components with new information. The EFH descriptions and maps from this EFH 5-year Review satisfy these requirements. The two Alaska EFH Research Plan objectives met in the present work are 1) the development of EFH information for life stages and species not previously described and 2) the raising of EFH information levels from none or Level 1 (distribution) to Level 2 (habitat-related abundance) and Level 3 (habitat-related vital rates).

In addition to satisfying the requirements and objectives above, the present work addresses the MSA requirement to meet the standards of best available scientific information stipulated in NMFS National Standard 2 – Scientific Information 50 CFR 600.315. Among the steps we took to advance EFH descriptions in Alaska while meeting the standards of best available science were to update length-based life stage definitions from the extant scientific literature and to extend the dataset analyzed in the last EFH 5-year Review with the five most recent years of data collected on the RACE-GAP summer bottom trawl surveys. We refined and advanced the SDM modeling approaches endorsed in the last 5-year Review by adding two SDMs to the suite of constituent models. We added a negative binomial GAM (GAM_{nb}) to address overdispersion in the data and we included a presence-absence GAM (paGAM) to model binary distribution information. In addition, we shifted the response variable from transformed CPUE to numerical abundance which facilitated skill testing among the constituent SDMs. In response to SSC input and facilitated by the shift to abundance as the response variable, we instituted an ensemble modeling approach for describing EFH in this Review, using skill testing to identify the best performing SDMs. The SDM ensemble approach provides a robust modeling framework for predicting abundance. These advances and refinements improved the scope and quality of our data products.

As described in Iterative Review (2.0) above, at key junctures during this project, after presenting methods and preliminary results to the SSC, we have received and incorporated constructive feedback to improve the analyses and results of this project (Table A1.1). In June 2020, we presented many of the modeling refinements listed above and received the suggestion that led to using ensemble modeling to combine the best-performing constituent SDMs. In April 2021, we presented preliminary results from these ensembles to the SSC, discussed the use of model fit metrics, and demonstrated the application of Level 3 EFH information. All of the feedback we received was addressed and much of it was integrated into our subsequent modeling efforts. We have also demonstrated methods and presented preliminary results to the Council's Plan Teams on several occasions (JGPT meetings in September 2020 and 2021, JGPT in November 2021, CPT in May 2021, and CPT in January 2022), receiving and responding to their feedback and expert opinions.

An innovation we introduced in this review cycle was an extensive review of our modeling methods and preliminary EFH descriptions and maps by stock assessment scientists and other species experts early enough in the process to incorporate their feedback in the final results. We also worked closely with the stock assessment community to coordinate the timing of this review process with their rigid annual stock assessment cycle so that we could incorporate their reviews into our final products reported in this Discussion Paper and in the three regional Technical Memoranda (Attachments 3-5). This was intentionally designed as an iterative process with EFH analysts in close and regular communication with stock assessment author reviewers to answer questions and to reach mutual agreement over issues raised in the review process. As with the feedback received from the SSC and the Plan Teams, this review process with the stock assessment authors improved our data products while strengthening stock authors' confidence in our EFH descriptions. We are grateful for the large amount of effort these teams brought to bear to improve this work.

The ensemble modeling approach we used to describe EFH in the present work provides several advantages. Ensemble modeling combines multiple, best-performing constituent SDMs. We have learned from our work on this project that certain classes of SDMs have tendencies to over- or under-predict abundance. For example, the MaxEnt model tends to over-estimate the total area of suitable habitat while the hGAM tends to be more restrictive. Since the ensemble provides what is essentially a weighted average of SDM outcomes, it often appears to produce more plausible predictions of EFH than single SDMs in isolation. We anticipate because of this that our ensemble framework will also be robust to changes in underlying data and will readily accept new or additional SDMs for testing and evaluation; both traits are advantageous for future EFH 5-year Reviews. One of our strong recommendations for future EFH ensembles is the addition of non-GAM SDMs to the suite of candidate models (e.g., boosted regression trees or random forest models) to expand the modeling perspectives represented in the present ensemble which favors GAMs (i.e., constituent model candidates in the present formulation are MaxEnt and 4 GAMs).

Predictor variables measured in or modeled from the habitats sampled were selected for their potential to influence species distribution and abundance in those areas. This provides a rationale for using SDMs containing habitat-related variables to predict North Pacific species distribution and abundance to model EFH in Alaska, and gives us confidence that the model predictions reflect the influences of habitat and environment on the distribution and abundance of the species modeled. For instance, in the Bering Sea, geographic location, bottom depth, and bottom temperature were the most common top contributors to the deviance explained by the ensembles confirming what is already known from other research (e.g., Laman et al. 2018, Stevenson and Lauth 2019) and supporting our intention that our models plausibly reflect reality. To expand the capabilities of the ensemble to link habitat factors with distribution and abundance, we added relevant terrain metrics to the suite of predictors used to parameterize the models (i.e., bathymetric position index and rockiness).

This body of work represents a significant advancement of the SDM approach for mapping EFH accepted after the 2017 EFH 5-year Review for Alaska. The ensemble modeling approach developed here, along with the other refinements described in this document, will provide a robust and flexible framework for future EFH descriptions. In addition, the ensembles developed here provide valuable information that can be extended to stock assessment and other EBFM efforts; the Alaska EBFM Roadmap Implementation Plan (NMFS 2018) promotes this “value-added” concept around applying EFH and habitat science to areas of resource management. An example of extending the utility of this EFH work can be found in the GOA walleye pollock Ecosystem and Socioeconomic Profiles (ESP) in the Stock Assessment and Fishery Evaluation (SAFE) Reports. Shotwell et al. (2019) include SDMs developed for EFH component 1 during the 2017 EFH 5-Year Review (Laman et al. 2018) and GOAIERP (Pirtle et al. 2019) in their GOA walleye pollock ESP. Recent studies have also applied these SDMs to developing stock-specific indicators for the ESPs (Shotwell et al. *in press*), to test hypotheses around groundfish recruitment processes in the GOA (Goldstein et al. 2020), and to assess changes in spatial-temporal species distribution and abundance in the Bering Sea under future climate scenarios (Rooper et al. 2021) and on more dynamic and short term time scales (Barnes et al. *in review*).

3.5 Future Recommendations

As we developed our modeling approaches for the present work and participated in multiple peer and expert reviews in a variety of venues, we have identified recommendations that could be considered for future EFH 5-year Reviews. These recommendations fall into three categories:

1. Prioritize and improve EFH for select species
2. Increase the scope and applicability of EFH research
3. Improve process and communication.

The complete list of these recommendations is incorporated into the three regional Technical Memoranda (Attachments 3-5), which provides more detailed descriptions of the pathways we, the EFH component 1 analysts, recommend. Table 1 of each FR section of those reports summarizes recommendations about data sources that should be explored for improving SDM estimates of distribution and abundance, Table 2 contains covariates to explore and potential sources for covariate data, and Table 3 (reproduced below as Table 18) summarizes the recommendations. We summarize and briefly discuss key recommendations in the three categories below.

3.5.1.1 Prioritize and improve EFH for select species

The existing methodology for describing and mapping EFH works well for most species. For others, approaches need to be modified in order to better capture drivers of distribution and abundance and generate habitat descriptions and maps. These approaches may involve incorporating new datasets (for fish distribution, environmental covariates, or life history parameters), or the development of modeling approaches that are amenable to their distributions (e.g., modeling at a broader spatial scale). For some of these species, the need for model improvements has been discussed (Attachments 3-5); in the future it is important to have both modeling and communication processes in place for these species. These may include agreed-upon differences in the modeling approach depending on data needs and performance of ensembles developed in previous EFH 5-year Reviews. There are several pathways by which EFH could be improved for the species that need it; we recommend leveraging existing species distribution data, environmental data, and life history information in cases when more life stages could be modeled, investing in the means to combine disparate datasets (e.g., non bottom trawl surveys), and incorporating a broader diversity of models in the ensembles used to describe EFH. We also encourage the continued exploration of quantitative methods that allow for model fitting and fit comparisons when there are data limitation issues; e.g., using soap-film smoothers in *mgcv* to better model edge areas that are less frequently sampled.

3.5.1.2 Increase scope and applicability of EFH research

Ongoing discussions with the SSC and stock assessment authors have identified conceptual frameworks that should be considered in the future for developing, evaluating, and utilizing EFH descriptions and maps. Considering how EFH is defined in terms of scale and ecological function could improve the utility of this concept for management. The present working definition of EFH equates the area containing 95% of the total estimated occupied habitat with EFH (NMFS 2005[41]), and core EFH area as the area containing 50% of occupied habitat. In the present work, occupancy was defined as areas with >5% probability of an encounter based on the RACE-GAP bottom trawl survey data. However, this definition may not be as ecologically meaningful for highly mobile species, or those with a high degree of uncertainty in the estimate of their population density. For example, the distribution of highly mobile predators might be more strongly impacted by prey availability than by environmental conditions. It may also not be a useful metric if a shrinking proportion of their population is available to the bottom trawl survey, as is the case for species with poleward-shifting distributions. As models describing and predicting species distribution and abundance (density or biomass) become more tightly and realistically linked to habitat and environmental change, there may be opportunity to reconsider how EFH is defined, potentially arriving at a more objective and constrained (less open to interpretation) definition that could be better applied across species and regions.

[41] https://repository.library.noaa.gov/view/noaa/17391

3.5.1.3 Improve process and communication

Improving methodological approaches and clearly communicating them is a high priority. Review and input by the Council's SSC, Plan Teams, the stock assessment authors, and other stakeholders is an important part of the iterative EFH 5-year Review process. Expert peer-reviews in particular can help identify cases where methodological changes are needed to account for species with lower quality data or low availability to the surveys where survey data have been used to model and map EFH. Additionally, the EFH process involves communicating model results to a broad stakeholder audience and adapting models when appropriate based on feedback. For example, a species with poor model fits or low stock assessment author confidence in the EFH map might be evaluated using a different SDM, or certain data requirements might be identified early that would lead to that species being modeled differently. Each EFH 5-year Review is an opportunity to improve the process and communication.

We are proud of the process and communication improvements that we implemented during this EFH 5-year Review to improve coordination and collaboration between SDM EFH analysts and stock assessment authors. We have implemented SSC suggestions from 2021 about communicating methods and results, including providing descriptions of ensemble modeling methods and probability thresholds, clear descriptions of data including data transformations and timeframes, and summaries of skill testing results. We (AKRO and AFSC) hosted a stock assessment author summit in January 2021 to discuss and co-develop the review process of the current and new EFH descriptions and maps. We set a timeline that worked for all parties and agreed on the content to be reviewed and the methods, which was well communicated and executed in an approachable process for the reviewers. In past EFH 5-year Reviews, current EFH descriptions and maps in the FMPs were provided to stock assessment authors with the new EFH maps for review. In this EFH Review, as the SDM ensemble EFH methods represent a significant advancement over the 2017 SDM EFH approach, and expert peer-review is an important part of the iterative EFH 5-year Review process; we provided the stock assessment authors with the complete set of regional SDM ensemble EFH methods (3 regions) and species results chapters (118 chapters). Stock assessment authors are considered subject matter experts, whose input was used to ground truth EFH information, including improving the modeling methodology in general and for their species. We recommend that an agreement be reached at the beginning of next 5-year Review regarding the process and scope for stock-assessment author review, in a way that remains feasible for the EFH analytical team.

In terms of carrying out and communicating throughout the EFH process, we recommend improvements to communicating uncertainty about estimates of species abundance and distribution. This involves improving ways to evaluate uncertainty in model predictions and ways to communicate that uncertainty in EFH descriptions. We recommended the development of scientific guidance for thresholds in EFH mapping and testing them, adding more avenues for communication (including communicating with stakeholders to develop simulation approaches for testing different management strategies and data collection practices), and streamlining workflows and reproducibility to make code accessible and reproducible.

Finally, we recommend forming an expert working group with the objective of developing and publishing a peer-reviewed manuscript providing clear and objective guidance to the SSC ahead of the next EFH 5-year Review for constructing EFH from SDMs within the regulatory framework of the MSA and EFH Final Rule. This may encompass an evaluation of thresholds and percentile areas applied to the SDMs and EFH maps, including the selection of the EFH area or subarea used to support the EFH component 2 fishing effects analysis.

Table 18. Summary table of future recommendations for EFH research to advance EFH component 1 descriptions and maps, and how EFH component 1 outputs are evaluated and applied to management.

Area of research	Improvement/advancement	Taxa with potential EFH improvement
Prioritize and improve EFH for select species	Leverage existing species distribution data to expand spatial scope and improve predictions in existing EFH maps	Species where higher-quality EFH information is needed (current maps contradict expert experience; model fits are relatively low compared to other species modeled)
	Leverage environmental data	All (especially species where higher-quality EFH information is needed)
	Improve life history information with best available science	All (especially crab species)
	Expand and improve existing SDM EFH mapping to include species and life stages in the nearshore (e.g., at appropriate spatial resolutions)	Many EFH species and their prey that inhabit nearshore habitats
	Develop methodology for combining disparate datasets	Species where higher-quality EFH information is needed
	Develop process studies to inform EFH descriptions and maps (e.g., vital rates, movement, population dynamics)	All
	Consider diverse constituent models	Species where higher-quality EFH information is needed; especially those with EFH level 1 information only
Increase scope and applicability of EFH research	Describe prey species habitat (EFH component 7)	Most groundfish, especially those with diets more specialized on forage
	Expand to EFH Levels 3 and 4	All
	Continue to advance and apply dynamic SDM methods in development to map and forecast shifts in EFH and spatial stock structure to improve climate responsive approaches to EFH and EBFM	All
Improve process and communication	Communicate confidence in EFH designations/boundaries	All
	Develop thresholds for mapping EFH with SDMs and SDM EFH applied to the Fishing Effects analysis (e.g., thresholds applied), through research and an expert work group, and communicate this guidance to the SSC prior to the launch of the next EFH 5-year Review.	All
	Add more opportunities for communication	All
	Streamline workflows and reproducibility	All

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5 APPENDICES

- Appendix 1: EFH component 1 analyst responses to requests and recommendations by the Council's Scientific and Statistical Committee (SSC), Joint meeting of the Groundfish Plan Teams (JGPT), and Crab Plan Team (CPT), provided in the minutes from meetings during the 2022 EFH 5-year Review to date and the 2017 EFH 5-year Review (SSC only).

- Appendix 2: Summaries of the SDM results developed for the 2022 EFH 5-year Review.

- Appendix 3: EFH comparisons between the SDMs, EFH areas and subareas, EFH maps, and EFH Levels of the 2017 and 2022 EFH 5-year Reviews.

- Appendix 4: SDM performance metrics chosen by the Laman et al study, additional metrics considered by this study, and additional metrics requested for consideration by SSC.

5.1 Appendix 1

5.1.1 EFH Analyst Responses to Iterative Reviews by SSC and Plan Teams

Appendix 1 provides EFH component 1 analyst responses to requests and recommendations by the Council's Scientific and Statistical Committee (SSC), Joint meeting of the Groundfish Plan Teams (JGPT), and Crab Plan Team (CPT), provided in the minutes from meetings during the 2022 EFH 5-year Review to date (Table A1.1)—

- SSC June 2020: Review of the proposed EFH component 1 SDM methods and preliminary results examples for the 2022 EFH 5-year Review.
- JGPT September 2020: Review of the proposed EFH component 1 SDM methods and preliminary results examples for the 2022 EFH 5-year Review.
- SSC April 2021: Review of the EFH component 1 plan for the 2022 EFH 5-year Review.
- CPT May 2021: Review of the EFH component 1 plan for the 2022 EFH 5-year Review.
- JGPT September 2021: Review of the results of the stock assessment author (SA) review of EFH component 1 in the FMP EFH documents, 2017 EFH maps, draft ensemble SDM EFH methods and results, and draft 2022 EFH maps, with EFH component 1 analyst planned response and recommendations.
- SSC October 2021: Review of JGPT report on EFH component 1 September 2021 agenda item.
- JGPT November 2021: Review of the iterative review process of EFH component 1 and SA review report with EFH analyst communications, recommendations, and responses.

As an opportunity to strengthen this work, SSC and Plan Teams provided input regarding study methods, progress to date, and planned research products to support new EFH component 1 information for the 2022 EFH Review, which the Laman et al. study and the other three contributing EFH component 1 studies (see Introduction 1) have taken into account to update their approach.

EFH analyst responses are summarized in Table A1.1 and referenced throughout this document. In some cases, more extensive responses are provided in the document (e.g., Appendix 2 Table A2.1).

Also included in Appendix 1 (5.1) are EFH component 1 analyst responses to SSC's request for "an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle" (Table A1.1 item 6b). SSC minutes from the 2017 process include the following meetings: February 2015, April 2016, October 2016, December 2016, and April 2017 (Table A1.2).

Table A1.1. EFH component 1 analyst responses to requests and recommendations (item) by the Council's Scientific and Statistical Committee (SSC), Joint meeting of the Groundfish Plan Teams (JGPT), and Crab Plan Team (CPT), provided in the minutes from meetings with an EFH agenda item scheduled or otherwise reported for review in 2020 and 2021, including (1) SSC June 2020, (2) JGPT September 2020, (3) SSC April 2021, (4) CPT May 2021, (5) JGPT September 2021, (6) SSC October 2021 (JGPT reporting to SSC; EFH agenda item not scheduled), and (7) JGPT November 2021.

Item	Description	Response
1: SSC June 2020 Meeting		
1a	SSC requested justification for selection of the final models using RMSE (root mean square error) or other skill testing metrics.	Methods describe how RMSE is used as an indicator of the best-performing model and model elimination steps are clear (see Cross Validation and Skill Testing 3.2.5).
1b	SSC recommended consideration of error distributions that are better suited to over-dispersed data (e.g., negative binomial).	To address overdispersion in the data, a negative binomial Generalized Additive Models (GAM) is now included among ensemble constituents (see Statistical Modeling 3.2.4).
1c	SSC recommended that analysts define thresholds for excluding or denoting areas where uncertainty is high (e.g., ratio of estimated response to uncertainty).	Species distribution model (SDM) prediction uncertainty (coefficient of variation (CV)) was mapped and areas of high uncertainty were compared with the SDM prediction maps (see Ensemble Models and Uncertainty 3.2.6).
1d	SSC suggested consideration of ensemble methods that weight EFH prediction across candidate SDMs with similar out-of-sample predictive performance (weighting based on out-of-sample predictive skill may be the most applicable).	Out of sample skill testing was used to select the best performing models and relative RMSE weighting was used for constituent models in the ensemble (see Cross Validation and Skill Testing 3.2.5).
1e	SSC supported continued exploration of alternative SDM approaches across species, regions, and life stages (e.g., presence-absence GAM (paGAM), hurdle GAM, GAM, and MaxEnt).	A negative binomial GAM was added to address overdispersion. An ensemble method including skill testing of constituent models was applied (see Statistical Modeling 3.2.4).
1f	SSC supported the following: Response variable of numerical abundance with area swept (effort) as an offset in the SDM; Out-of-sample skill testing for arbitrating among candidate SDMs; Cross-validation through repeated sampling of testing and training datasets; Use of the complementary log-log (cloglog) link to relate abundance to occurrence, which facilitates skill testing; Use of RMSE for skill testing.	All of these supported methods are used in the Laman et al. SDM EFH approach for the 2022 EFH 5-year Review and SSC's support is appreciated. In addition to facilitating skill testing among models by standardizing model units, use of the cloglog link places formerly Level 1 (distribution) models producing a response variable in units of probability (paGAM and MaxEnt) in units of Level 2 (abundance) (see What's New 3.1 and Methods 3.2).
1g	SSC supported continued exploration of static and dynamic predictor covariates.	ROMS covariates have been updated for the Bering Sea and Gulf of Alaska (GOA; bottom temperature data only) based on ROMS data available at the time the SDMs needed to be run for the 2022

Item	Description	Response
		Review. Terrain covariates have also been added to the suite of predictors in this Review. Continued development of static and dynamic covariates for subsequent EFH Reviews is a priority (see Future Recommendations 3.5).
1h	SSC supported research permitting description of Level 3 EFH.	All four studies contributing new EFH component 1 information for the 2022 Review describe and identify Level 3 EFH for a subset of species in the Gulf of Alaska, Bering Sea, Aleutian Islands, and Arctic: Laurel et al. *in prep* (Gulf of Alaska); Laman et al. *in prep* (Gulf of Alaska, Bering Sea, Aleutian Islands); Marsh et al. *in prep* (Arctic); Shotwell et al. *in prep* (Gulf of Alaska). The Laman et al. study will be presented to SSC in February 2022 and the other studies are currently scheduled for review in June 2022 (see Introduction 1). The Laman et al. study has included an EFH Level 3 mapping case study for Pacific cod settled early juveniles in the GOA in this Discussion Paper (see this Results Case Study 3.3.2.7).
1i	SSC encouraged expanded efforts to include additional sources of information to describe and define EFH.	Contributing studies have considered expanding approaches to include additional sources of information to describe and identify EFH for the 2022 Review. Given the timeline of the four contributing studies, most recommendations to expand efforts are best applied as new EFH component 1 information for a future EFH 5-year Review (e.g., additional SDM covariates, data types, and surveys; untrawlable and other underrepresented habitat areas).
1j	SSC encouraged consideration of EFH in timeblocks and discussed the need to move to a more dynamic definition of EFH given recent and rapid changes observed in the environment and species distributions.	EFH is currently described and identified for North Pacific Council managed species as habitat-related species distribution and abundance, using SDMs with survey data from the 1980s through 2014 (2017 Review) and SDM ensembles through 2019 (2022 Review). The EFH final rule requires EFH maps to be in FMPs, thus requiring an FMP amendment to change the maps (50 CFR 600.815(a)(1)(i) “FMPs must include maps of the geographic locations of EFH or the geographic boundaries within which EFH for each species and life stage is found.”). NMFS Office of Sustainable Fisheries funded a separate study to develop dynamic SDM using species in the Bering Sea as a case study (e.g., at 1, 3, 5, 10, and 15-year timeblocks) to explore and map EFH at more

Item	Description	Response
		dynamic temporal scales (Barnes et al. *in review*). These dynamic SDM methods may be another informative approach to describe and map habitat related species distribution and abundance and EFH, given recent and rapid changes observed in the environment and species distributions. In a future EFH Review, Barnes et al. (*in review*) can potentially complement the SDM EFH approach that the Laman et al. study has advanced for the 2022 Review. The Laman et al. study builds on the SDM EFH approach of the 2017 Review (Laman et al. 2018) with new data and refined methods.
1k	SSC encouraged consideration of whether co-mapping or directly incorporating vital rates (for EFH Level 3) within SDM is the best approach, while highlighting that it ultimately depends upon the underlying assumptions and questions.	All four studies that describe and identify EFH Level 3 for the 2022 Review use a *raster product approach*, where raster-1 is the SDM prediction of habitat-related abundance, raster-2 is temperature-dependent growth rate (or, another temperature-dependent vital rate), and the resulting product of the two rasters is an EFH Level 3 map (see EFH Level 3 3.2.8.6). These new EFH Level 3 maps can be used to further interpret the EFH Level 1 or Level 2 descriptions and maps, e.g., to consider corresponding areas of high growth and habitat-related abundance.
1l	SSC noted the immense progress in EFH modeling and hopes that these analyses will be considered in stock assessments and analyses supporting stock assessments, particularly habitat suitability and how it may pertain to recruitment and spawning locations. At a minimum, these efforts should be able to contribute to the stock assessment process and ongoing EBFM efforts, including through the ESPs.	Thank you. NMFS Alaska greatly appreciates SSC's review and input that has strengthened this work and the EFH 5-year Review process overall!
2: JGPT September 2020 Meeting		
2a	JGPT supported an ensemble modelling approach, but requested that authors also present each of the ensemble members so reviewers can see the influence or contribution and the variability associated with each.	Results of each ensemble constituent and the final ensemble are reported in the individual species results chapters in the three regional Technical Memoranda (Attachments 3-5). The case study examples provided in this document use this reporting approach (see Regional Case Studies 3.3.2).
2b	JGPT noted that in the bridging example of sablefish EFH, it would be useful to see the iterative changes that result from each change or addition.	Additional bridging examples, similar to that presented for sablefish to SSC and JGPT in 2020, are provided in the case study examples (see Regional Case Studies 3.3.2, e.g., Figure 26) and refined since

Item	Description	Response
		2020 to clarify the iterative changes that result from each major step in our approach.
2c	JGPT noted that all the information should be available to the stock assessment authors, in an easily accessible way (e.g., AKFIN).	Analysts provided the EFH component 1 information to individual stock assessment authors for their species for review of the draft methods and results and revisions were subsequently made available. We are publishing three regional Technical Memoranda with the final methods and results (Attachments 3-5), our spatial data (e.g., SDM covariates and prediction rasters) will be archived at NOAA NCEI, the EFH maps will be available to visualize and download from the Alaska and National EFH Mappers, and our R code will be archived at GitHub; all sources are also accessible to the public.
3: SSC April 2021 Meeting		
3a	SSC requested review of the SDM model results.	This information is provided in the Results 3.3, Appendices 5, and Attachments 6, including the three regional Technical Memoranda (Attachments 3-5) and EFH map overlay figures (Attachment 2).
3b	SSC requested an overview of discussions or recommendations from stock assessment authors.	A timeline of the iterative review process with the stock assessment authors is provided in the Iterative Review section 2 and discussions and recommendations are provided in detail in the SA Review Report (Attachment 1).
3c	SSC requested a summary of important covariates across species.	This information is comprehensively summarized in Appendix 2 Table A2.1, and provided in the Regional Case Studies 3.3.2 and Synthesis 3.3.3 sections of the Results. The three regional Technical Memoranda (Attachments 3-5) provide this information for each species' life stage modeled by the Laman et al. study for the 2022 EFH 5-year Review.
3d	SSC requested a report on model convergence issues and how these were addressed.	This information is provided in Cross Validation and Skill Testing 3.2.5 and in the three regional Technical Memoranda (Attachments 3-5). SDM constituents were weighted by RMSE in the final ensembles.
3f	SSC requested a summary report on data limitations that created important model performance issues.	SDM performance was affected when species life stage prevalence was low (i.e., they were not commonly encountered). The SDMs developed for the 2017 and 2022 EFH 5-year reviews relied primarily on RACE-GAP summer bottom trawl survey data to map

Item	Description	Response
		EFH for species' life stages in the summer season. We recommend adding species data from additional surveys and seasons in a combined survey data approach for certain species' life stages in the SDM ensembles, which will require additional research to accomplish for a future EFH 5-year Review (see Conclusions 3.4 and Future Recommendations 3.5). In the 2017 EFH 5-year Review, fishery-dependent data were used to map EFH in Fall, Winter, and Spring. Expanding how seasonality is addressed in EFH mapping and applied to the SDM ensembles will also require additional research. However, we are confident that expanding analyses to include additional data sources where appropriate and improving how seasonality is addressed will broaden our understanding of habitat related species distribution and abundance and spatial stock structure for North Pacific species.
3g	SSC requested a summary of results from the skill testing and resulting ensemble member weights, by species.	This information is comprehensively provided in each species results chapter of the three regional Technical Memoranda (Attachments 3-5) and the Regional Case Studies 3.3.2.
3h	SSC requested that analysts highlight potential seasonality issues and large changes in core areas when compared to previous results.	The Laman et al. study provided a summary of ensemble performance and EFH areas compared to the single SDMs developed for the 2017 EFH 5-year Review in Appendix 3 (Table A3.2) and visually with overlay maps of the 2017 and 2022 EFH areas (Regional Case Studies 3.3.2, Appendix 3 Figure A3.1, and Attachment 2). Addressing "seasonality issues" is beyond the scope of the 2022 EFH 5-year Review and could be addressed if additional research on the topic is completed for a future EFH 5-year Review (see item 3f).
3i	SSC requested discussion on weighting issues encountered with the ensemble modeling.	See SSC June 2020 Meeting (item 1d) and methods on Cross Validation and Skill Testing 3.2.5.
3j	SSC requested discussion of other pertinent issues identified by the stock assessment and EFH authors.	This request is comprehensively addressed in the SA Review Report (Attachment 1) and can be discussed during SSC review scheduled for February 2022.
4: CPT May 2021 Meeting		
4a	CPT noted that the timing of the stock assessment author review (May to September) works well for the crab stock assessment	EFH component 1 analysts prioritized development of crab EFH documents and provided the crab stock assessment author and

Item	Description	Response
	cycle and recommended that crab EFH documents be prioritized to allow assessment author-expert partnerships more time for review before September CPT deadlines.	expert reviewers with this information at the launch of the stock assessment author review of EFH component 1 in May ahead of the groundfish documents.
4b	CPT expressed concern that EFH is defined by species, and data products are of limited utility for identifying EFH specific to each crab stock. The CPT would be interested to see smaller scale SDMs produced for individual crab stocks.	EFH is described and identified by species within the management unit of the FMP (50 CFR 600.805(b)). Analysts would like to work with crab stock assessment authors and species experts to improve how EFH is described and mapped for crabs in preparation for a future EFH 5-year Review. Crab scientists are also encouraged to submit proposals to the NMFS AKRO and AFSC annual EFH Research Plan request for funding.
5: JGPT September 2021 Meeting		
5a	JGPT noted that the modeling efforts that are informing the 2022 EFH review were developed in the 2017 Alaska EFH Research Plan after the completion of the 2017 EFH review.	The Laman et al. study was funded by NMFS AKRO and AFSC to develop new EFH information and maps using new and existing data and modernized species distribution modeling methods (e.g., SDM ensembles and skill testing) for life stages of groundfish and crabs in the EBS, AI, and GOA, building on the SDM approach of the 2017 EFH 5-year Review, and focusing on the summer season maps (applied to the FE analysis) using primarily RACE-GAP summer bottom trawl survey data. This approach reflects the Alaska EFH Research Plan objectives identified to accomplish, following the 2017 EFH 5-year Review (Sigler et al. 2017).
5b	JGPT noted that the stock assessment authors were presented with only one performance metric for their EFH reviews. The EFH team presented three new performance metrics to the Teams, which they used to update the EFH descriptions. This information was not included for the assessment authors' reviews, and the EFH team does not plan to provide an opportunity for author review of that information.	Input received from SAs in their review of the Laman et al. study draft methods and results, combined with EFH component 1 analyst's own internal review, led to revised methods of assessing model performance which is described and reported in this Discussion Paper and in the three regional Technical Memoranda. Analysts clearly communicated to JGPT at this meeting that this information would be provided to SAs for additional review. Following this meeting, analysts worked closely with all eight SAs who had expressed concern over ensemble performance for their species and subsequently made the revised results available to all SAs in early November 2021 in an email invitation sent through their supervisors that revised materials were available upon request. EFH analysts note that no SDM performance metrics were provided

Item	Description	Response
		to SAs for review of the new EFH component 1 SDMs in the 2017 EFH 5-year Review. EFH analysts and SAs co-developed the SA review approach for the 2022 Review to be more comprehensive, including review of the draft methods and results, which has improved the process overall, collaboration between EFH analysts and SAs, and the final results for the 2022 EFH 5-year Review of EFH component 1. Details of this process and communications are available in Attachment 1.
5c	JGPT noted that EFH analysts stated that with the exception of both of the Pacific sleeper shark EFH descriptions, all of the stocks were going to be put forward, including the poor performers. Stocks for which the models were poor performers will be reviewed on a case by case basis, and the EFH analysts will present results to the authors for further review.	Following this meeting and as clearly communicated at the meeting, EFH analysts contacted all eight stock authors who expressed concern over model performance in their review of the draft methods and results (see item 5b). In a limited number of cases where necessary (two stock authors and four species), EFH analysts worked with the stock author to come up with a revised plan for these species. Pacific sleeper sharks and two species in the GOA other rockfish complex that did not have an EFH map in 2017 were removed from consideration for the 2022 EFH 5-year Review. GOA Atka mackerel ensemble constituents were examined and the ensemble was revised to improve the overall result. See Attachment 1 for the details of these iterative reviews and communications between stock authors and EFH analysts.
5d	JGPT noted that during the September 2020 JGPT review of EFH component 1, the Teams requested to see the following two items for the 2021 September JGPT review, and the Teams again recommended that they be provided: present each of the ensemble members so reviewers can see the influence or contribution of each ensemble member, and the variability associated with each, and see the iterative changes that result from each change or addition.	In response to the JGPT September 2020 requests, EFH analysts provided a table of SDM constituent and final ensemble performance in each species results chapter that was provided to the SAs for their review in May – September prior to the JGPT September 2021 meeting (see JGPT 2020 item 2a). In addition, bridging figures that show iterative changes that result from each method change or addition are provided in the Regional Case Studies 3.3.2. While it is beyond the capacity of the Laman et al. study to provide bridging examples for all species' life stages modeled, it may be possible to automate the development of these figures for a future EFH 5-year Review (see JGPT 2020 item 2b).
5e	JGPT noted that the inclusion of alternative data sources (e.g., AFSC longline survey) is critical for the definition of EFH for some species. This need, while noted in the 2017 EFH Review,	The Laman et al. study was funded by NMFS AKRO and AFSC to meet the objectives of the Alaska EFH Research Plan (Sigler et al. 2017), following the 2017 Review. The SAs pointed out in their

Item	Description	Response
	was not included in the 2017 EFH Research Plan. The Teams recommended that the inclusion of alternative data sources be prioritized for future EFH model developments.	review the importance of including additional data sources in the EFH SDMs for certain species, which was very helpful. The EFH analysts have included this recommendation for additional research needed for a future EFH 5-year Review. SAs are invited to participate in research proposals with EFH analysts or independently to see that this area of methods development is accomplished (see Future Recommendations 3.5).
5f	JGPT recommended adding comparison of previous SDMs (when available) to the EFH description documents (e.g., how has the spatial extent changed from the previous EFH?).	EFH analysts provided the 2017 and 2022 EFH maps to the SAs for their review (May – September 2021) prior to the JGPT September 2021 Meeting (see Attachment 1). As this comparison is important, EFH analysts have since provided a table to compare 2017 and 2022 model performance and changes in EFH area and the core EFH subarea as well as overlay maps to improve visual interpretation of EFH area changes (see Appendix 3 5.3 and Attachment 2).
5g	JGPT recommended consideration of the time series extent in future modeling efforts, as species distributions and habitat can shift over the 30+ year time series of the data.	Use of species catch data from a long time series (e.g., 1993-2019 for groundfish subadults and adults in the GOA) in SDMs to map EFH is for the purpose of ensuring that the EFH maps represent the long term distribution of the stock over a range of environmental conditions (and per SSC guidance in the 2017 EFH Review). SSC noted (June 2020 item 1j) that developing EFH over more dynamic temporal scales would be helpful to see species distribution shifts when present. EFH analysts agree with SSC and JGPT that this information would be useful and extensible to other stock assessment and EBFM information needs beyond EFH. A study is in progress (Barnes et al. *in review*) to develop dynamic SDM methods to address this for EFH species. Additional research should also be developed. SAs are invited to develop collaborative proposals with EFH analysts to help address this.
6: SSC October 2021 Meeting (based on JGPT reporting to SSC; an EFH agenda item was not scheduled)		
6a	SSC requested an updated timeline of EFH component 1 review/input be provided.	This is addressed in the Iterative Review 2 section of this document and in detail in the SA Review Report (Attachment 1).
6b	SSC requested an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.	This is provided for EFH component 1 in Appendix 1 Table A1.2. The EFH component 2 analysts should also address this request.

Item	Description	Response
6c	SSC requested a summary of major EFH elements that have already been peer reviewed (e.g., the fishing effects model and research outlined in the initial June 2019 work plan).	See item 6a. The EFH component 2 analysts should also address this request.
6d	The SSC strongly recommends the EFH team incorporate author comments into the full review for February 2022 and requests a summary of detailed comments made by assessment authors and EFH team responses as appropriate.	The SA review of the Laman et al. study draft methods and results provided helpful input as part of the iterative review process of the 2022 EFH 5-year Review. EFH component 1 analysts have incorporated SA review input that was possible to include at this time, and based on their input, have made several future research recommendations to develop for a subsequent EFH 5-year Review. EFH analysts have documented the details of communication with SAs during their review of EFH component 1 (see Future Recommendations 3.5 and the SA Review Report Attachment 1).
6e	SSC requested a table showing the current EFH levels and proposed changes under the new methodology.	See the Results section 3.3 of this document for a summary of EFH Level advancements available for the 2022 EFH 5-year Review and Appendix 3 Table A3.1 that compares EFH Levels between the 2017 and 2022 EFH 5-year Reviews.
6f	SSC requested information on the importance of habitat covariates in the SDM for each species and life stage. The purpose of this request is to evaluate whether habitat covariates statistically influence the distribution and abundance of North Pacific groundfish and crab life stages.	This information is provided in Appendix 2 Table A2.1. See also SSC April 2021 item 3c.
6g	SSC requested a clear description of the data used for each model ensemble: e.g., description of data sources, data transformations, new data sets not previously considered, and input data time periods.	This information is provided in the Methods section 3.2 and the three regional Technical Memoranda (Attachments 3-5) with detail for each region.
6h	SSC requested a description of how complexes are being treated in the analysis.	See the methods on EFH Maps 3.2.8 and three regional Technical Memoranda (Attachments 3-5) where this information is provided in detail for each region. Please also refer to the SA review of EFH component 1 report (Attachment 1) for how individual species complexes were addressed by region.
6i	SSC requested a description of the ensemble modeling methods and a summary of member model fits, including a description of the probability thresholds used to characterize species presence and absence.	See the methods on Ensemble Models and Uncertainty 3.2.6, Regional Case Studies 3.3.2, and the three regional Technical Memoranda (Attachments 3-5) where this information (e.g., ensemble constituent performance) is provided in detail for each region and species' life stage modeled. Appendix 2 Table A2.2 is a

Item	Description	Response
		comprehensive summary of 2022 model performance metrics and EFH areas.
6j	SSC requested consideration of using a Precision Recall (PR) AUC and F1 scores as an alternative to ROC AUC.	EFH analysts provided these additional model performance metrics in Appendix 4 Table A4.1, which SSC requested be considered in October 2021 (first SSC review of draft methods was June 2020).
6k	SSC requested a table showing species and life stage-specific ensemble fit metrics (i.e., Spearman's rho, AUC, Deviance Explained) and including PR AUC and F1 metrics.	This information is comprehensively provided in Appendix 2 Table A2.2 for the three comprehensive and common performance metrics that the Laman et al. study chose for evaluating and presenting their final results, which were implemented following internal review and the SA review that concluded September 2021. See item 6j, regarding SSC's request to consider additional performance metrics PR AUC and F1, which are reported in Appendix 4 Table A4.1, along with additional metrics that had also been considered by the Laman et al. study.
6l	SSC requested providing maps that allow comparison of new results with 2017 results and total changes in area values (e.g., total % change and km^2).	The Laman et al. study provided a summary of ensemble performance and EFH areas compared to the single SDMs developed for the 2017 EFH 5-year Review in Appendix 3 (Table A3.2) and visually with overlay maps of the 2017 and 2022 EFH areas (see Regional Case Studies 3.3.2, Appendix 3 Figure A3.1, and Attachment 2) (see SSC April 2021 items 3f and 3h).
6m	SSC requested maps showing the regions used to extract spatial outputs (core EFH) for the fishing effects analyses and clear description of thresholds.	EFH area percentile maps showing the regions used to extract spatial outputs (core EFH area; CEA) for the fishing effects (FE) analysis are provided for each species' life stage modeled in the three regional Technical Memoranda (Attachments 3-5) and in the Discussion Paper with the species case studies (see Results 3.3); thresholds applied are described in the methods on EFH Mapping 3.2.8,. In addition, overlay maps of the 2017 and 2022 EFH areas are provided in Attachment 2, with the species case studies (see Results 3.3 section), and described in Appendix 3 (Figure A3.1). Overlay maps of the 2017 and 2022 CEA will be provided for SSC review of the EFH component 2 FE analysis. **An outcome of an EFH 5-year Review meeting of NMFS (G. Harrington, J. Olson, J. Pirtle) and Council (D. Evans) staff on November 16, 2021 was a recommendation that EFH component 2 analysts will present the 2017 and 2022 CEA overlay maps (provided by the**

Item	Description	Response
		EFH component 1 analysts in December 2021) with the FE analysis at the SSC's June 2022 meeting.
6n	Explain the data used to train the models and predict EFH and the changes in the data used in the 2017 and new EFH maps.	See Methods 3.2, where this information is comprehensively described in several subsections.
7: JGPT November 2021 Meeting		
7a	JGPT thanked the EFH analysts for the development and application of the EFH models, the responsiveness to stock assessment author reviews, and for the detailed report describing the review process.	Thank you. NMFS Alaska greatly appreciates JGPT's review and input and that of the stock assessment authors and species experts, which has strengthened this work and the EFH 5-year Review process overall.

Table A1.2. EFH component 1 (descriptions and identification) analyst responses to SSC's request for "an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle" (Table A1.1 6b). SSC minutes from the 2017 process include the following meetings: (1) February 2015[42], (2) April 2016[43], (3) October 2016[44], (4) December 2016[45], and (5) April 2017[46].

Item	Description	Response
1: SSC February 2015 Meeting		
1	SSC reviewed the document *Defining EFH for Alaska Groundfish Species using Species Distribution Modeling (SDM)*. "SSC supports the use of SDMs for predicting species distributions" and provided suggestions and comments to strengthen the proposed research to update to EFH designations based on the use of SDMs for the 2017 EFH 5-year Review.	At this early stage of the 2017 EFH 5-year Review EFH component 1 analysts had incorporated several SSC suggestions and comments into the SDM methods. SSC's February 2015 review of the proposed SDM EFH approach for the 2017 Review is similar to their review of the revised SDM EFH approach for the 2022 Review in June 2020.
2: SSC April 2016 Meeting		
2	SSC reviewed an update to EFH designations based on the use of SDMs to define EFH. **"SSC supports the use of SDMs for predicting species' distributions . . . revisions to EFH definitions in the FMPs are warranted and the FMPs should be amended"**. SSC acknowledged "there is still work to be done to allow this new approach to identifying EFH to reach its full potential" and the SSC provided comments and recommendations.	See items 2a-c relevant to EFH component 1.
2a	SSC is pleased to see the analysts' efforts to provide seasonal EFH maps. Given the immense array of data types by season that were employed, the SSC recommends that the authors develop a data-support-product to characterize the number, type and age of samples supporting model predictions. This will be particularly important for the identification of data gaps that warrant future research priority and clear acknowledgement when EFH is used in subsequent analyses.	EFH C1 analysts developed SDM-based EFH maps for four seasons in the 2017 EFH 5-year Review. Although a "data-support-product" was not necessarily developed for the 2022 EFH 5-year Review, analysts have comprehensively described the data used in their methods in text and Tables, which are provided in this document (see Methods) and in the three regional NMFS Technical Memoranda (Attachments 3-5).

[42] SSC February 2015 Meeting
[43] SSC April 2016 Meeting
[44] SSC October 2016 Meeting
[45] SSC December 2016 Meeting
[46] SSC April 2017 Meeting

Item	Description	Response
2b	SSC understands that EFH information will become available online. The ability for users to select species for display and to overlay species' distributions would extend the value of this information.	NMFS AKR launched the Alaska EFH Mapper in November, 2018 (one year in advance of the new SDM-based EFH maps from the 2017 EFH 5-year Review being published on the NMFS National EFH Mapper). The AK Mapper allows users to select species' life stages for display and to overlay species' distributions and other features not available on the National Mapper such as displaying EFH maps by EFH Level. An update to the AK Mapper is underway by AKR in preparation for the new set of EFH maps from the 2022 EFH 5-year Review. This update is anticipated to significantly improve user experience and with new links to the spatial data used to develop the 2022 EFH maps. EFH component 1 analysts and AFSC HEPR are also working on an archiving workflow for EFH spatial data with NOAA NCEI.
2c	SSC is aware of considerable new information that is sufficient to warrant an update of EFH for the Arctic FMP. Although updating EFH for the Arctic may not be urgent owing to the lack of commercial fisheries in this region, this information may be timely with regards to other ongoing and planned activities in the Arctic.	The Arctic FMP was updated following the 2017 EFH 5-year Review with new EFH maps based on species distribution from surveys (Simpson et al. 2017). As Arctic EFH maps are not currently based on SDMs, a study by Marsh et al. (*in prep*) has developed SDMs for life stages of Arctic FMP species, including EFH Level 1, 2, and 3 descriptions and maps, concurrently with the Laman et al. study, to improve the quality of Arctic species EFH information. This study also provides interannual comparisons of EFH area in warm and cold years. New EFH information from this study available for the 2022 EFH 5-year Review will be presented to SSC in June 2022.
3: SSC October 2016 Meeting		
3	SSC reviewed information on EFH descriptions available for the 2017 EFH 5-year Review (component 1) and the analysis of the effects of fishing on EFH for component 2 at this meeting. In April 2016, SSC recommended that revisions to EFH definitions in the FMPs were warranted and the FMPs should be amended.	See items 3a-c as related to EFH component 1. EFH component 2 analysts will provide a Discussion Paper for the SSC February 2022 meeting that will address the SSC's October 2021 request for an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.

Item	Description	Response
3a	SSC encouraged the EFH component 1 analysts to examine the use of acoustic data as input to the EFH descriptions (e.g., for walleye pollock).	EFH component 1 analysts responded following the April 2016 meeting that the acoustic data were not considered in SDMs for the 2017 EFH 5-year Review because the analysts were trying to identify a common method that applied to all species. EFH component 1 analysts in the 2022 EFH 5-year Review agree that midwater acoustic data could be valuable to describe and map EFH for species such as walleye pollock and prey of EFH species such as capelin (EFH component 7 – habitat of EFH species' prey). Since e.g., AFSC MACE surveys also occur during Fall, Winter, and Spring in addition to Summer, these surveys could provide useful seasonal data for certain species. Additional research is required to integrate midwater acoustic survey data (i.e., collected along transects) within the SDM ensemble approach to mapping EFH in the 2022 EFH 5-year Review.
3b	SSC recommended that sediment type be considered as a co-variate in the GAM models.	EFH component 1 analysts included sediment grainsize (*phi*) as a covariate in for species' life stages modeled in the EBS, and a seafloor rockiness covariate for species' life stage modeled in the Aleutian Islands and the Gulf of Alaska in SDMs developed for the 2022 EFH 5-year Review (see the Habitat Covariates subsection of the Methods and Attachments 3-5).
3c	SSC encouraged evaluation of the predictive skill of the models (especially in the fall, winter and spring).	EFH C1 analysts introduced new model skill testing methods in the 2022 EFH 5-year Review (see What's New and Methods sections and results summary Tables provided in the Appendices).
4: SSC December 2016 Meeting		
4	SSC reviewed revisions to the methods for assessing the impacts of habitat disturbance on fish and crab stocks for the component 2 fishing effects analysis, and the report on Impacts to Essential Fish Habitat from Non-fishing Activities in Alaska (EFH component 4) at this meeting.	EFH component 2 analysts will provide a Discussion Paper for the SSC February 2022 meeting that will address the SSC's October 2021 request for an overview of SSC recommendations from the 2017 EFH process and the degree to which these were addressed for the current EFH review cycle.
5: SSC April 2017 Meeting		

Item	Description	Response
5	SSC reviewed the EFH Omnibus Amendment at this meeting. SSC agreed that the EFH Omnibus Amendment Environmental Assessment (EA) was ready for public review. SSC made several recommendations to improve EFH EA readability and access to all information necessary for decision making. Improved documentation of the information considered in the assessment will assist greatly in the 2022 EFH Review and the Center for Independent Expert review planned for 2019-20.	EFH analysts will take the SSC's recommendations into account as NMFS develops the 2022 EFH 5-year Review Summary Report (e.g., Simpson et al. 2017) and the 2022 EFH EA. We thank SSC for the comprehensive, iterative reviews of the EFH information in development for the 2017 and 2022 EFH 5-year Reviews, where input has strengthened the work products and process overall.

5.2 Appendix 2

5.2.1 2022 EFH 5-Year Review SDM Results Summaries

Appendix 2 provides summaries of the SDM results developed for the 2022 EFH 5-year Review—

- Table A2.1 is a summary of the most influential covariates by region and species' life stage for each ensemble or SDM produced during the 2022 EFH 5-year Review (Appendix 1 Table A1.1 items 3c and 6f).
- Table A2.2 is a summary of the 2022 SDM results by region for each species' life stage modeled, including N, RMSE, performance metrics (ρ, AUC, and PDE), EFH area (km^2), and core EFH area (km^2).
- See the results Synthesis 3.3.3.

Table A2.1. Summary of the covariates that were most influential (highest percent contribution) by region and species' life stage for each model (ensemble or SDM) produced during the 2022 EFH 5-year Review (Appendix 1 Table A1.1 items 3c and 6f). Terms is the total number of covariates in the model. First, Second, and Third represent the three most influential covariates for that model and their percent contribution (% Contrib.) to the deviance explained by the model. BPI = bathymetric position index, location = geographic location, and *phi* = sediment grainsize.

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	Alaska skate	subadult	13	Location	Bottom Depth	Aspect Eastness	66.3
AI	Alaska skate	adult	15	Bottom Depth	Location	Bottom Current SD	51.4
AI	Aleutian skate	subadult	15	Location	Bottom Depth	Bottom Currents	59.0
AI	Aleutian skate	adult	14	Bottom Depth	Bottom Currents	Location	68.3
AI	arrowtooth flounder	early juvenile	15	Location	Tidal Maximum	Bottom Depth	54.2
AI	arrowtooth flounder	subadult	15	Location	Bottom Depth	Tidal Maximum	75.6
AI	arrowtooth flounder	adult	15	Bottom Depth	Location	Bottom Currents	67.5
AI	Atka mackerel	subadult	15	Bottom Depth	Location	Tidal Maximum	76.4
AI	Atka mackerel	adult	15	Bottom Depth	Location	Bottom Currents	67.6
AI	Dover sole	subadult	15	Location	Bottom Depth	Bottom Currents	56.3
AI	Dover sole	adult	15	Bottom Depth	Location	Bottom Currents	67.0
AI	dusky rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	71.0
AI	dusky rockfish	adult	15	Location	Bottom Currents	Bottom Depth	51.2
AI	English sole	adult	15	Tidal Maximum	Bottom Depth	BPI	46.5
AI	flathead sole	early juvenile	15	Location	Bottom Depth	BPI	56.7
AI	flathead sole	subadult	15	Location	Bottom Depth	Tidal Maximum	58.0
AI	flathead sole	adult	15	Location	Bottom Depth	Tidal Maximum	61.0
AI	giant octopus	all	15	Sponge Presence	Bottom Temperature	Bottom Depth	45.5
AI	golden king crab	all	15	Bottom Depth	Bottom Currents	Location	55.8
AI	Greenland turbot	adult	13	Bottom Depth	Bottom Temperature	Location	72.9

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	harlequin rockfish	adult	15	Location	Bottom Currents	Bottom Depth	43.7
AI	Kamchatka flounder	subadult	15	Bottom Currents	Location	Bottom Current SD	53.3
AI	Kamchatka flounder	adult	15	Bottom Depth	Location	Bottom Currents	54.7
AI	mud skate	subadult	15	Bottom Depth	Location	Rockiness	75.7
AI	mud skate	adult	15	Bottom Depth	Aspect Northness	Location	60.1
AI	northern rock sole	early juvenile	15	Bottom Depth	Location	Bottom Currents	68.1
AI	northern rock sole	subadult	15	Bottom Depth	Location	Bottom Currents	78.5
AI	northern rock sole	adult	15	Bottom Depth	Location	Bottom Current SD	74.2
AI	northern rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	75.3
AI	northern rockfish	adult	15	Bottom Depth	Location	Bottom Current SD	73.7
AI	Pacific cod	subadult	15	Bottom Depth	Location	Bottom Current SD	67.1
AI	Pacific cod	adult	15	Bottom Depth	Location	Tidal Maximum	62.1
AI	Pacific ocean perch	early juvenile	15	Bottom Depth	Location	Bottom Currents	53.9
AI	Pacific ocean perch	subadult	15	Bottom Depth	Location	Aspect Eastness	54.8
AI	Pacific ocean perch	adult	15	Bottom Depth	Location	Bottom Currents	85.7
AI	red king crab	all	15	Location	Bottom Depth	Tidal Maximum	55.7
AI	rex sole	subadult	15	Bottom Depth	Location	Tidal Maximum	64.7
AI	rex sole	adult	15	Bottom Depth	Location	Aspect Northness	59.1
AI	rougheye blackspotted complex	subadult	15	Bottom Depth	Location	Bottom Currents	68.7
AI	rougheye blackspotted complex	adult	15	Bottom Depth	Location	Bottom Current SD	69.4
AI	sablefish	subadult	15	Bottom Depth	Location	Bottom Temperature	76.4
AI	sablefish	adult	15	Bottom Depth	Location	Curvature	69.3
AI	shortraker rockfish	subadult	15	Bottom Depth	Location	Bottom Currents	80.6

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
AI	shortraker rockfish	adult	15	Bottom Depth	Location	Bottom Current SD	67.8
AI	shortspine thornyhead	subadult	14	Bottom Depth	Location	Bottom Currents	74.0
AI	shortspine thornyhead	adult	14	Bottom Depth	Location	Aspect Northness	82.2
AI	southern rock sole	subadult	13	Location	Bottom Depth	Bottom Currents	97.2
AI	southern rock sole	adult	15	Location	Bottom Depth	Bottom Currents	93.5
AI	walleye pollock	early juvenile	15	Bottom Depth	Location	Aspect Northness	55.7
AI	walleye pollock	subadult	15	Bottom Depth	Location	Rockiness	62.6
AI	walleye pollock	adult	15	Bottom Depth	Location	Bottom Currents	74.3
AI	whiteblotched skate	subadult	14	Location	Bottom Currents	Tidal Maximum	73.8
AI	whiteblotched skate	adult	15	Location	Tidal Maximum	Bottom Depth	79.7
EBS	Alaska plaice	early juvenile	11	Location	Bottom Temperature	Bottom Currents	84.5
EBS	Alaska plaice	subadult	15	Bottom Depth	Location	Bottom Temperature	72.8
EBS	Alaska plaice	adult	15	Location	Bottom Depth	*phi*	73.9
EBS	Alaska skate	subadult	15	Location	Bottom Temperature	Bottom Depth	74.8
EBS	Alaska skate	adult	15	Bottom Temperature	Bottom Depth	Location	76.6
EBS	Aleutian skate	subadult	15	Location	Bottom Currents	Bottom Depth	58.1
EBS	Aleutian skate	adult	15	Bottom Depth	Location	*phi*	77.5
EBS	arrowtooth flounder	early juvenile	14	Location	Bottom Depth	Bottom Temperature	82.0
EBS	arrowtooth flounder	subadult	15	Location	Bottom Temperature	Bottom Depth	89.7
EBS	arrowtooth flounder	adult	15	Location	Bottom Temperature	Bottom Depth	84.0
EBS	Atka mackerel	adult	15	Location	Bottom Depth	Slope	78.6
EBS	Bering skate	subadult	15	Bottom Depth	Location	Bottom Currents	79.3
EBS	Bering skate	adult	15	Location	Bottom Depth	Bottom Currents	79.1
EBS	Bering flounder	subadult	14	Location	Bottom Temperature	Bottom Depth	80.4

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Bering flounder	adult	15	Location	Bottom Temperature	Bottom Depth	81.5
EBS	big skate	subadult	14	Location	Bottom Temperature	Bottom Depth	82.8
EBS	blue king crab	all	14	Location	*phi*	Bottom Depth	62.0
EBS	butter sole	adult	14	Location	Bottom Currents	Bottom Temperature	63.8
EBS	deepsea sole	all	10	Bottom Depth	Bottom Currents	Bottom Current SD	87.0
EBS	Dover sole	subadult	14	Location	Bottom Depth	*phi*	71.9
EBS	Dover sole	adult	14	Bottom Depth	Location	Bottom Currents	72.0
EBS	flathead sole	early juvenile	15	Location	Bottom Depth	Bottom Temperature	66.5
EBS	flathead sole	subadult	15	Location	Bottom Depth	*phi*	83.6
EBS	flathead sole	adult	15	Location	Bottom Depth	Bottom Temperature	79.2
EBS	giant octopus	all	14	Location	Bottom Depth	Bottom Currents	75.0
EBS	Greenland turbot	subadult	15	Location	Bottom Temperature	Bottom Depth	72.0
EBS	Greenland turbot	adult	15	Bottom Depth	Location	Bottom Temperature	71.5
EBS	Kamchatka flounder	subadult	15	Location	Bottom Depth	Bottom Temperature	80.9
EBS	Kamchatka flounder	adult	15	Bottom Depth	Location	Bottom Temperature	84.2
EBS	longhead dab	all	12	Location	Bottom Depth	Bottom Currents	87.0
EBS	mud skate	subadult	15	Location	Bottom Depth	Bottom Currents	59.4
EBS	mud skate	adult	12	Location	Bottom Depth	Bottom Currents	64.3
EBS	northern rock sole	early juvenile	14	Bottom Depth	Location	Bottom Temperature	77.2
EBS	northern rock sole	subadult	13	Bottom Depth	Location	Bottom Temperature	80.4
EBS	northern rock sole	adult	13	Location	Bottom Depth	*phi*	79.8
EBS	northern rockfish	adult	14	Bottom Depth	Location	Bottom Currents	64.8
EBS	Pacific cod	early juvenile	15	Location	Bottom Temperature	Bottom Depth	77.1
EBS	Pacific cod	subadult	14	Location	Bottom Depth	Bottom Temperature	68.5

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Pacific cod	adult	15	Bottom Temperature	Bottom Depth	Location	80.5
EBS	Pacific ocean perch	early juvenile	13	Bottom Depth	Location	Sponge Presence	70.4
EBS	Pacific ocean perch	subadult	15	Bottom Depth	Location	*phi*	72.2
EBS	Pacific ocean perch	adult	12	Bottom Depth	Location	Bottom Currents	86.5
EBS	red king crab	all	15	Tidal Maximum	Bottom Depth	Location	70.1
EBS	rex sole	early juvenile	14	Location	Bottom Depth	Pennatulacean Presence	54.3
EBS	rex sole	subadult	15	Location	Bottom Depth	Bottom Currents	72.3
EBS	rex sole	adult	15	Location	Bottom Depth	Bottom Currents	69.8
EBS	rougheye blackspotted complex	subadult	14	Bottom Depth	Location	Bottom Currents	78.0
EBS	rougheye blackspotted complex	adult	11	Bottom Depth	Location	Bottom Currents	89.2
EBS	sablefish	early juvenile	14	Location	Bottom Temperature	Pennatulacean Presence	77.9
EBS	sablefish	subadult	15	Location	Bottom Depth	Bottom Temperature	69.6
EBS	sablefish	adult	15	Bottom Depth	Location	Bottom Currents	79.0
EBS	Sakahalin sole	subadult	13	Location	Tidal Maximum	Bottom Temperature	81.1
EBS	Sakahalin sole	adult	13	Location	Tidal Maximum	Bottom Depth	77.1
EBS	shortraker rockfish	subadult	14	Bottom Depth	Location	Slope	79.5
EBS	shortraker rockfish	adult	15	Bottom Depth	Bottom Currents	Slope	58.2
EBS	shortspine thornyhead	subadult	11	Bottom Depth	Location	Bottom Currents	89.1
EBS	shortspine thornyhead	adult	15	Bottom Depth	Location	Bottom Currents	67.7
EBS	snow crab	all	15	Location	Bottom Depth	Bottom Temperature	77.4
EBS	starry flounder	subadult	15	Location	Bottom Temperature	*phi*	75.2
EBS	starry flounder	adult	15	Location	Bottom Depth	Bottom Temperature	61.8

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
EBS	Tanner crab	all	15	Location	Bottom Depth	*phi*	84.8
EBS	walleye pollock	early juvenile	13	Location	Bottom Depth	Tidal Maximum	76.8
EBS	walleye pollock	subadult	15	Location	Bottom Temperature	Bottom Depth	82.6
EBS	walleye pollock	adult	15	Location	Bottom Temperature	Bottom Depth	78.9
EBS	whiteblotched skate	subadult	11	Bottom Depth	Location	Tidal Maximum	88.5
EBS	whiteblotched skate	adult	13	Bottom Depth	Location	Tidal Maximum	81.4
EBS	yellowfin sole	early juvenile	15	Location	Bottom Depth	Bottom Currents	91.1
EBS	yellowfin sole	subadult	15	Bottom Depth	Location	Bottom Currents	84.1
EBS	yellowfin sole	adult	15	Bottom Depth	Location	Bottom Currents	80.4
GOA	Alaska plaice	subadult	15	Bottom Depth	Location	Tidal Maximum	67.1
GOA	Alaska plaice	adult	15	Location	Bottom Depth	Tidal Maximum	69.9
GOA	Alaska skate	subadult	15	Location	Bottom Depth	BPI	62.8
GOA	Alaska skate	adult	9	Location	Bottom Temperature	Bottom Current SD	76.5
GOA	Aleutian skate	subadult	14	Bottom Depth	Location	Bottom Temperature	79.9
GOA	Aleutian skate	adult	15	Location	Bottom Depth	Bottom Temperature	73.8
GOA	arrowtooth flounder	early juvenile	10	Tidal Maximum	Aspect Eastness	Aspect Northness	60.7
GOA	arrowtooth flounder	subadult	15	Bottom Depth	Location	Bottom Temperature	77.1
GOA	arrowtooth flounder	adult	15	Bottom Depth	Location	Bottom Temperature	62.3
GOA	Atka mackerel	subadult	14	Bottom Depth	Location	Sponge Presence	68.6
GOA	Atka mackerel	adult	14	Location	Bottom Depth	Bottom Currents	79.8
GOA	Bering skate	subadult	15	Location	Bottom Depth	Bottom Temperature	72.1
GOA	Bering skate	adult	15	Location	Bottom Depth	Bottom Temperature	73.3
GOA	big skate	subadult	15	Bottom Depth	BPI	Location	74.7
GOA	big skate	adult	14	Bottom Depth	Location	Bottom Temperature	67.8

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	butter sole	adult	15	Bottom Depth	Rockiness	Location	64.7
GOA	Dover sole	subadult	15	Location	Bottom Depth	Bottom Currents	79.7
GOA	Dover sole	adult	15	Bottom Depth	Location	Bottom Currents	72.2
GOA	dusky rockfish	subadult	15	Bottom Depth	Location	Tidal Maximum	57.7
GOA	dusky rockfish	adult	15	Bottom Depth	Rockiness	Location	62.6
GOA	English sole	early juvenile	8	Bottom Depth	Slope	Aspect Eastness	96.3
GOA	English sole	subadult	11	Bottom Depth	Tidal Maximum	Location	70.3
GOA	English sole	adult	15	Bottom Depth	Location	Tidal Maximum	63.2
GOA	flathead sole	early juvenile	12	BPI	Bottom Depth	Tidal Maximum	58.0
GOA	flathead sole	subadult	15	Location	Bottom Depth	Tidal Maximum	62.2
GOA	flathead sole	adult	15	Location	BPI	Bottom Depth	68.9
GOA	giant octopus	all	15	Location	Sponge Presence	Bottom Depth	62.2
GOA	greenstriped rockfish	adult	15	Location	Bottom Depth	Bottom Temperature	72.3
GOA	harlequin rockfish	subadult	15	Location	Bottom Depth	Sponge Presence	54.7
GOA	harlequin rockfish	adult	15	Bottom Depth	Location	Rockiness	51.3
GOA	longnose skate	subadult	15	Bottom Depth	Location	Bottom Temperature	68.8
GOA	longnose skate	adult	13	Location	Bottom Depth	BPI	74.2
GOA	northern/southern rock soles	early juvenile	10	Bottom Depth	Tidal Maximum	Slope	84.7
GOA	northern rock sole	subadult	15	Bottom Depth	Location	Bottom Temperature	87.7
GOA	northern rock sole	adult	15	Bottom Depth	Location	Bottom Temperature	89.8
GOA	northern rockfish	subadult	15	Bottom Depth	Location	Rockiness	60.6
GOA	northern rockfish	adult	15	Location	Bottom Depth	Bottom Currents	60.1
GOA	Pacific cod	early juvenile	11	Bottom Depth	Aspect Eastness	BPI	83.2

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	Pacific cod	subadult	15	Bottom Depth	Location	Tidal Maximum	75.5
GOA	Pacific cod	adult	15	Bottom Depth	Location	Bottom Temperature	78.1
GOA	Pacific ocean perch	early juvenile	10	Bottom Depth	Bottom Temperature	Tidal Maximum	64.2
GOA	Pacific ocean perch	subadult	15	Bottom Depth	Location	Rockiness	66.8
GOA	Pacific ocean perch	adult	15	Bottom Depth	Location	Tidal Maximum	69.6
GOA	Pacific sanddab	all	14	Location	Bottom Temperature	Tidal Maximum	72.3
GOA	Petrale sole	subadult	15	Location	Bottom Temperature	Tidal Maximum	52.5
GOA	Petrale sole	adult	15	Location	Bottom Depth	Bottom Temperature	72.4
GOA	pygmy rockfish	all	15	Rockiness	Location	Sponge Presence	58.3
GOA	quillback rockfish	adult	14	Bottom Depth	Bottom Temperature	Bottom Currents	59.0
GOA	redbanded rockfish	subadult	15	Bottom Depth	Location	Slope	75.7
GOA	redbanded rockfish	adult	15	Bottom Depth	Location	Bottom Temperature	68.7
GOA	redstripe rockfish	subadult	15	Location	Bottom Depth	Rockiness	64.7
GOA	redstripe rockfish	adult	15	Location	Bottom Depth	Rockiness	59.1
GOA	rex sole	early juvenile	12	Tidal Maximum	Aspect Northness	BPI	60.1
GOA	rex sole	subadult	15	Bottom Depth	Location	Tidal Maximum	79.7
GOA	rex sole	adult	15	Bottom Depth	Location	Tidal Maximum	72.7
GOA	rosethorn rockfish	subadult	14	Location	Bottom Depth	Bottom Temperature	70.2
GOA	rosethorn rockfish	adult	15	Location	Bottom Currents	Bottom Temperature	68.7
GOA	rougheye blackspotted complex	subadult	15	Bottom Depth	Location	Slope	77.3
GOA	rougheye blackspotted complex	adult	15	Bottom Depth	Slope	Location	84.1
GOA	sablefish	early juvenile	11	Tidal Maximum	Aspect Northness	Bottom Temperature	54.9
GOA	sablefish	subadult	15	Bottom Depth	Bottom Temperature	Location	67.2

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	sablefish	adult	15	Bottom Depth	Location	Bottom Currents	75.9
GOA	sand sole	adult	15	Bottom Depth	Bottom Temperature	Bottom Currents	66.5
GOA	sharpchin rockfish	subadult	14	Location	Bottom Depth	Sponge Presence	58.0
GOA	sharpchin rockfish	adult	14	Bottom Depth	Location	Rockiness	60.2
GOA	shortraker rockfish	subadult	14	Bottom Depth	Location	Bottom Currents	83.0
GOA	shortraker rockfish	adult	15	Bottom Depth	Bottom Currents	Location	78.5
GOA	shortspine thornyhead	subadult	15	Bottom Depth	Location	Sponge Presence	73.8
GOA	shortspine thornyhead	adult	15	Bottom Depth	Location	Bottom Currents	83.5
GOA	silvergray rockfish	subadult	14	Location	Bottom Depth	Rockiness	60.8
GOA	silvergray rockfish	adult	15	Location	Bottom Depth	Bottom Current SD	65.0
GOA	slender sole	all	15	Location	Bottom Depth	Bottom Temperature	70.2
GOA	southern rock sole	subadult	15	Bottom Depth	Location	Tidal Maximum	82.6
GOA	southern rock sole	adult	15	Bottom Depth	Location	Tidal Maximum	86.6
GOA	spiny dogfish	subadult	15	Location	Bottom Temperature	Bottom Currents	73.1
GOA	spiny dogfish	adult	15	Location	Bottom Temperature	Bottom Currents	70.5
GOA	starry flounder	early juvenile	10	Bottom Depth	Curvature	Slope	92.0
GOA	starry flounder	subadult	15	Bottom Depth	Location	Bottom Temperature	63.5
GOA	starry flounder	adult	15	Bottom Depth	Location	BPI	76.6
GOA	walleye pollock	early juvenile	11	BPI	Bottom Depth	Aspect Eastness	58.9
GOA	walleye pollock	subadult	15	Bottom Depth	Location	Tidal Maximum	62.3
GOA	walleye pollock	adult	15	Bottom Depth	Location	Rockiness	73.9
GOA	yelloweye rockfish	subadult	15	Bottom Depth	Sponge Presence	Location	59.7
GOA	yelloweye rockfish	adult	14	Bottom Depth	Location	Rockiness	59.4
GOA	yellowfin sole	early juvenile	12	Bottom Depth	Aspect Northness	Tidal Maximum	84.5

Region	Species	Life stage	Terms	First	Second	Third	% Cont.
GOA	yellowfin sole	subadult	15	Bottom Depth	Location	Tidal Maximum	77.3
GOA	yellowfin sole	adult	15	Location	Bottom Depth	Tidal Maximum	73.1

Table A2.2. 2022 SDM results by region for each species' life stage modeled. Metrics shown are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). EFH area (spatial domain containing the top 95% of occupied habitat) and core EFH area (EFH subarea containing the top 50% of occupied habitat (applied to the EFH fishing effects analysis in the 2017 EFH 5-year Review) are provided (km^2).

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Alaska skate	subadult	102	0.42	0.20	0.80	0.25	25,700	13,500
AI	Alaska skate	adult	149	0.65	0.25	0.81	0.27	48,600	25,600
AI	Aleutian skate	subadult	367	0.61	0.26	0.76	0.19	56,000	29,500
AI	Aleutian skate	adult	221	0.35	0.21	0.76	0.18	23,400	12,300
AI	arrowtooth flounder	early juvenile	341	1.5	0.35	0.90	0.56	36,800	19,300
AI	arrowtooth flounder	subadult	3,503	84.5	0.63	0.79	0.40	77,700	40,900
AI	arrowtooth flounder	adult	3,118	42.9	0.49	0.75	0.29	77,700	40,900
AI	Atka mackerel	subadult	1,312	1,130	0.54	0.72	0.38	77,700	40,900
AI	Atka mackerel	adult	2,030	1,190	0.52	0.65	0.36	77,700	40,900
AI	Dover sole	subadult	396	1.5	0.30	0.83	0.35	44,900	23,600
AI	Dover sole	adult	232	0.87	0.27	0.88	0.43	29,200	15,400
AI	dusky rockfish	subadult	108	1.4	0.20	0.88	0.32	36,800	19,400
AI	dusky rockfish	adult	380	9.2	0.27	0.78	0.44	64,700	34,100
AI	English sole	adult	50	1.5	0.23	0.98	0.82	10,400	5,500
AI	flathead sole	early juvenile	183	5.5	0.28	0.94	0.81	30,400	16,000
AI	flathead sole	subadult	1,279	72.8	0.60	0.89	0.72	69,400	36,500
AI	flathead sole	adult	1,374	13.5	0.56	0.86	0.48	67,800	35,700

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	giant octopus	all	682	0.81	0.20	0.67	0.09	72,000	37,900
AI	golden king crab	all	1,148	6.1	0.56	0.89	0.48	51,400	27,100
AI	Greenland turbot	adult	359	11.6	0.41	0.96	0.70	26,600	14,000
AI	harlequin rockfish	adult	111	23.4	0.18	0.86	0.40	62,000	32,600
AI	Kamchatka flounder	subadult	2,207	22.6	0.58	0.81	0.51	77,600	40,900
AI	Kamchatka flounder	adult	918	19.4	0.54	0.90	0.74	51,800	27,300
AI	mud skate	subadult	488	2.1	0.46	0.90	0.63	34,200	18,000
AI	mud skate	adult	290	0.41	0.28	0.82	0.26	36,600	19,200
AI	northern rock sole	early juvenile	154	0.57	0.25	0.89	0.38	32,900	17,300
AI	northern rock sole	subadult	1,901	42.3	0.73	0.90	0.62	69,500	36,600
AI	northern rock sole	adult	2,923	58.8	0.72	0.88	0.47	74,700	39,300
AI	northern rockfish	subadult	832	271	0.43	0.82	0.50	75,200	39,600
AI	northern rockfish	adult	2,063	779	0.56	0.68	0.42	77,700	40,900
AI	Pacific cod	subadult	2,872	34.1	0.47	0.74	0.28	74,100	39,000
AI	Pacific cod	adult	3,084	40.4	0.50	0.76	0.37	77,600	40,800
AI	Pacific ocean perch	early juvenile	722	68.8	0.36	0.80	0.38	69,600	36,600
AI	Pacific ocean perch	subadult	1,016	175	0.40	0.78	0.39	77,500	40,800
AI	Pacific ocean perch	adult	2,908	1,570	0.71	0.68	0.46	77,700	40,900
AI	red king crab	all	83	1.6	0.15	0.85	0.27	29,900	15,800
AI	rex sole	subadult	1,145	8.1	0.48	0.83	0.47	68,900	36,300

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	rex sole	adult	1,891	22.6	0.56	0.82	0.43	77,200	40,600
AI	rougheye blackspotted complex	subadult	1,058	10.9	0.53	0.88	0.51	65,600	34,500
AI	rougheye blackspotted complex	adult	711	19.4	0.52	0.94	0.76	34,800	18,300
AI	sablefish	subadult	472	9.7	0.43	0.93	0.54	41,400	21,800
AI	sablefish	adult	368	8.1	0.40	0.95	0.66	33,100	17,400
AI	shortraker rockfish	subadult	408	8.5	0.47	0.98	0.86	23,300	12,200
AI	shortraker rockfish	adult	514	6.1	0.48	0.96	0.76	27,400	14,400
AI	shortspine thornyhead	subadult	380	8.1	0.46	0.98	0.76	23,200	12,200
AI	shortspine thornyhead	adult	1,051	26.1	0.61	0.93	0.74	54,800	28,900
AI	southern rock sole	subadult	583	12.9	0.55	0.97	0.73	41,600	21,900
AI	southern rock sole	adult	763	11.0	0.62	0.97	0.81	42,300	22,200
AI	walleye pollock	early juvenile	198	4.8	0.23	0.86	0.37	54,300	28,600
AI	walleye pollock	subadult	1,525	324	0.41	0.75	0.40	77,700	40,900
AI	walleye pollock	adult	2,773	447	0.50	0.71	0.28	77,700	40,900
AI	whiteblotched skate	subadult	459	2.5	0.48	0.94	0.66	35,800	18,800
AI	whiteblotched skate	adult	544	2.1	0.49	0.92	0.72	37,000	19,500
EBS	Alaska plaice	early juvenile	272	4.1	0.25	0.97	0.69	2.00E+05	105,300
EBS	Alaska plaice	subadult	6,527	53.9	0.79	0.94	0.60	562,300	295,900
EBS	Alaska plaice	adult	8,684	111	0.81	0.92	0.56	660,400	347,600

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	Alaska skate	subadult	6,801	10.1	0.63	0.86	0.32	676,100	355,800
EBS	Alaska skate	adult	5,162	5.0	0.55	0.78	0.29	673,700	354,600
EBS	Aleutian skate	subadult	1,021	3.6	0.55	0.98	0.76	158,500	83,400
EBS	Aleutian skate	adult	207	0.44	0.30	0.96	0.57	59,000	31,000
EBS	arrowtooth flounder	early juvenile	1,975	8.6	0.56	0.93	0.55	339,100	178,500
EBS	arrowtooth flounder	subadult	5,669	119	0.84	0.95	0.69	524,200	275,900
EBS	arrowtooth flounder	adult	4,976	26.6	0.81	0.96	0.64	426,400	224,400
EBS	Atka mackerel	adult	72	0.69	0.09	0.85	0.28	26,200	13,800
EBS	Bering skate	subadult	1,232	2.0	0.52	0.93	0.60	240,300	126,400
EBS	Bering skate	adult	1,429	0.88	0.51	0.90	0.48	267,300	140,700
EBS	Bering sole	subadult	2,583	30.2	0.61	0.97	0.74	463,800	244,100
EBS	Bering sole	adult	2,966	29.6	0.64	0.96	0.67	458,500	241,300
EBS	big skate	subadult	62	0.11	0.17	0.96	0.58	6,700	3,500
EBS	blue king crab	all	1,650	8.0	0.47	0.93	0.52	472,600	248,700
EBS	butter sole	adult	177	13.7	0.20	0.98	0.60	124,000	65,200
EBS	deepsea sole	all	110	0.30	0.45	1.00	0.87	10,900	5,700
EBS	Dover sole	subadult	182	0.45	0.21	0.96	0.57	45,500	23,900
EBS	Dover sole	adult	91	0.37	0.30	0.99	0.73	13,200	7,000
EBS	flathead sole	early juvenile	4,794	36.6	0.60	0.86	0.44	629,500	331,300
EBS	flathead sole	subadult	9,501	186	0.83	0.90	0.66	680,900	358,300

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	flathead sole	adult	9,702	143	0.71	0.88	0.33	681,800	358,900
EBS	giant octopus	all	693	0.69	0.28	0.88	0.31	207,500	109,200
EBS	Greenland turbot	subadult	2,419	10.2	0.55	0.93	0.58	392,300	206,500
EBS	Greenland turbot	adult	1,974	4.2	0.53	0.95	0.70	241,800	127,300
EBS	Kamchatka flounder	subadult	5,055	23.4	0.77	0.94	0.55	443,700	233,500
EBS	Kamchatka flounder	adult	1,752	2.1	0.51	0.91	0.63	276,300	145,400
EBS	longhead dab	all	2,307	54.0	0.61	0.97	0.68	386,200	203,300
EBS	mud skate	subadult	169	0.52	0.31	0.98	0.83	24,600	12,900
EBS	mud skate	adult	147	0.43	0.28	0.98	0.69	25,700	13,500
EBS	northern rock sole	early juvenile	2,884	378	0.67	0.90	0.51	627,200	330,100
EBS	northern rock sole	subadult	7,020	716	0.86	0.82	0.65	674,800	355,100
EBS	northern rock sole	adult	7,790	472	0.82	0.89	0.49	672,800	354,100
EBS	northern rockfish	adult	89	9.1	0.15	0.97	0.71	83,800	44,100
EBS	Pacific cod	early juvenile	3,213	44.9	0.53	0.87	0.38	608,500	320,200
EBS	Pacific cod	subadult	12,889	118	0.58	0.80	0.24	680,500	358,200
EBS	Pacific cod	adult	11,853	20.5	0.48	0.79	0.15	675,700	355,600
EBS	Pacific ocean perch	early juvenile	95	1.2	0.17	0.97	0.59	61,500	32,400
EBS	Pacific ocean perch	subadult	131	1.9	0.18	0.98	0.56	83,900	44,100
EBS	Pacific ocean perch	adult	561	308	0.34	0.99	0.39	191,900	101,000
EBS	red king crab	all	3,376	74.6	0.67	0.95	0.52	363,900	191,500

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	rex sole	early juvenile	105	0.20	0.15	0.94	0.40	39,400	20,800
EBS	rex sole	subadult	1,849	9.1	0.52	0.95	0.65	262,100	137,900
EBS	rex sole	adult	2,171	9.8	0.56	0.95	0.77	233,100	122,700
EBS	rougheye blackspotted complex	subadult	208	0.82	0.28	0.99	0.78	40,500	21,300
EBS	rougheye blackspotted complex	adult	105	0.15	0.36	0.99	0.75	13,200	7,000
EBS	sablefish	early juvenile	59	0.21	0.12	0.94	0.37	28,300	14,900
EBS	sablefish	subadult	391	2.2	0.32	0.97	0.60	75,700	39,800
EBS	sablefish	adult	544	1.8	0.39	0.99	0.77	67,800	35,700
EBS	Sakhalin sole	subadult	476	16.5	0.29	0.98	0.63	309,900	163,100
EBS	Sakhalin sole	adult	225	2.1	0.22	0.97	0.68	199,900	105,200
EBS	shortraker rockfish	subadult	122	0.88	0.31	0.99	0.80	27,800	14,600
EBS	shortraker rockfish	adult	142	1.7	0.33	0.99	0.85	13,600	7,200
EBS	shortspine thornyhead	subadult	253	4.3	0.50	1.00	0.87	22,600	11,900
EBS	shortspine thornyhead	adult	696	16.0	0.55	1.00	0.92	47,700	25,100
EBS	snow crab	all	10,628	1,930	0.84	0.85	0.41	688,900	362,600
EBS	starry flounder	subadult	575	11.4	0.37	0.97	0.69	214,500	112,900
EBS	starry flounder	adult	1,619	19.2	0.51	0.96	0.58	357,000	187,900
EBS	Tanner crab	all	9,244	140	0.80	0.93	0.35	540,400	284,400
EBS	walleye pollock	early juvenile	9,367	463	0.55	0.75	0.14	672,200	353,800

Region	Species	Life stage	N	RMSE	*ρ*	AUC	PDE	EFH area	Core EFH area
EBS	walleye pollock	subadult	9,528	553	0.69	0.76	0.30	689,500	362,900
EBS	walleye pollock	adult	13,506	1,020	0.63	0.63	0.24	689,500	362,900
EBS	whiteblotched skate	subadult	224	1.8	0.34	0.99	0.72	33,300	17,500
EBS	whiteblotched skate	adult	201	0.34	0.33	0.98	0.69	30,800	16,200
EBS	yellowfin sole	early juvenile	2,134	191	0.57	0.97	0.65	504,100	265,300
EBS	yellowfin sole	subadult	9,289	977	0.90	0.95	0.63	617,900	325,200
EBS	yellowfin sole	adult	9,480	476	0.89	0.96	0.62	620,300	326,500
GOA	Alaska plaice	subadult	85	0.83	0.23	0.98	0.62	28,500	15,000
GOA	Alaska plaice	adult	442	3.6	0.38	0.97	0.71	87,500	46,100
GOA	Alaska skate	subadult	95	0.21	0.13	0.82	0.21	14,600	7,700
GOA	Alaska skate	adult	78	0.15	0.13	0.85	0.24	13,300	7,000
GOA	Aleutian skate	subadult	613	0.54	0.28	0.78	0.30	165,800	87,300
GOA	Aleutian skate	adult	147	0.19	0.17	0.83	0.25	30,600	16,100
GOA	arrowtooth flounder	early juvenile	1,825	--	--	0.79	--	242,500	127,600
GOA	arrowtooth flounder	subadult	7,390	276	0.64	0.70	0.28	281,800	148,300
GOA	arrowtooth flounder	adult	7,043	189	0.55	0.76	0.29	281,800	148,300
GOA	Atka mackerel	subadult	87	1.6	0.15	0.91	0.40	83,900	44,200
GOA	Atka mackerel	adult	700	143	0.33	0.85	0.35	233,800	123,100
GOA	Bering skate	subadult	401	0.33	0.27	0.84	0.28	113,600	59,800
GOA	Bering skate	adult	407	0.32	0.28	0.84	0.31	94,700	49,800

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	big skate	subadult	594	1.1	0.31	0.85	0.44	158,500	83,400
GOA	big skate	adult	195	0.20	0.19	0.86	0.27	37,300	19,600
GOA	butter sole	adult	881	30.1	0.46	0.93	0.54	204,900	107,900
GOA	Dover sole	subadult	3,710	17.4	0.61	0.83	0.46	281,300	148,000
GOA	Dover sole	adult	2,973	11.0	0.62	0.87	0.42	272,900	143,600
GOA	dusky rockfish	subadult	315	17.7	0.21	0.80	0.27	235,200	123,800
GOA	dusky rockfish	adult	1,061	53.1	0.40	0.83	0.28	264,000	138,900
GOA	English sole	early juvenile	56	--	--	0.99	--	39,300	20,700
GOA	English sole	subadult	116	2.3	0.20	0.95	0.57	55,700	29,300
GOA	English sole	adult	746	13.3	0.34	0.84	0.52	241,600	127,200
GOA	flathead sole	early juvenile	2,017	--	--	0.90	--	150,100	79,000
GOA	flathead sole	subadult	4,064	109	0.71	0.86	0.65	257,900	135,700
GOA	flathead sole	adult	4,201	63.3	0.72	0.88	0.54	257,900	135,700
GOA	giant octopus	all	459	0.33	0.20	0.75	0.15	134,900	71,000
GOA	greenstriped rockfish	adult	120	1.4	0.30	1.00	0.85	19,300	10,200
GOA	harlequin rockfish	subadult	102	14.6	0.16	0.92	0.50	170,600	89,800
GOA	harlequin rockfish	adult	514	71.3	0.31	0.88	0.44	254,800	134,100
GOA	longnose skate	subadult	1,058	0.63	0.28	0.74	0.15	233,800	123,100
GOA	longnose skate	adult	845	0.46	0.25	0.74	0.15	209,100	110,000
GOA	northern/southern rock sole	early juvenile	252	--	--	0.95	--	128,100	67,400

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	northern rock sole	subadult	1,854	57.3	0.68	0.96	0.68	182,200	95,900
GOA	northern rock sole	adult	1,980	25.0	0.68	0.95	0.58	190,700	100,400
GOA	northern rockfish	subadult	522	8.3	0.30	0.86	0.42	215,600	113,500
GOA	northern rockfish	adult	1,141	276	0.46	0.89	0.32	261,100	137,400
GOA	Pacific cod	early juvenile	354	--	--	0.95	--	124,800	65,700
GOA	Pacific cod	subadult	3,653	66.2	0.53	0.79	0.30	265,600	139,800
GOA	Pacific cod	adult	4,476	70.2	0.47	0.75	0.25	264,700	139,300
GOA	Pacific ocean perch	early juvenile	1,552	--	--	0.80	--	212,500	111,800
GOA	Pacific ocean perch	subadult	1,686	48.6	0.49	0.85	0.39	253,400	133,400
GOA	Pacific ocean perch	adult	2,992	692	0.65	0.81	0.39	281,500	148,100
GOA	Pacific sanddab	all	77	2.2	0.19	0.98	0.74	32,000	16,900
GOA	Petrale sole	subadult	59	0.32	0.18	0.98	0.56	15,400	8,100
GOA	Petrale sole	adult	271	1.3	0.29	0.96	0.65	64,600	34,000
GOA	pygmy rockfish	all	63	3.0	0.14	0.96	0.40	74,900	39,400
GOA	quillback rockfish	adult	73	0.44	0.17	0.96	0.51	17,600	9,300
GOA	redbanded rockfish	subadult	829	2.1	0.46	0.94	0.63	116,600	61,400
GOA	redbanded rockfish	adult	321	1.6	0.29	0.93	0.49	98,800	52,000
GOA	redstripe rockfish	subadult	133	7.2	0.20	0.95	0.52	95,400	50,200
GOA	redstripe rockfish	adult	234	47.9	0.25	0.94	0.65	214,500	112,900
GOA	rex sole	early juvenile	480	--	--	0.85	--	209,900	110,400

Region	Species	Life stage	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	rex sole	subadult	4,744	33.6	0.56	0.80	0.32	281,800	148,300
GOA	rex sole	adult	4,455	36.3	0.59	0.80	0.37	280,100	147,400
GOA	rosethorn rockfish	subadult	132	0.93	0.30	0.99	0.76	25,900	13,700
GOA	rosethorn rockfish	adult	186	2.5	0.40	0.99	0.82	29,600	15,600
GOA	rougheye blackspotted complex	subadult	2,178	20.4	0.62	0.90	0.57	258,000	135,800
GOA	rougheye blackspotted complex	adult	878	9.9	0.46	0.93	0.70	128,700	67,700
GOA	sablefish	early juvenile	959	--	--	0.84	--	235,800	124,100
GOA	sablefish	subadult	2,812	47.0	0.56	0.84	0.34	278,400	146,500
GOA	sablefish	adult	2,011	18.9	0.65	0.94	0.61	216,700	114,100
GOA	sand sole	adult	109	4.4	0.22	0.97	0.60	50,600	26,600
GOA	sharpchin rockfish	subadult	498	47.0	0.37	0.95	0.69	191,800	100,900
GOA	sharpchin rockfish	adult	425	97.9	0.34	0.95	0.54	218,600	115,100
GOA	shortraker rockfish	subadult	316	1.4	0.45	0.99	0.77	24,800	13,000
GOA	shortraker rockfish	adult	679	7.6	0.47	0.97	0.73	65,200	34,300
GOA	shortspine thornyhead	subadult	1,634	24.4	0.65	0.97	0.76	186,900	98,400
GOA	shortspine thornyhead	adult	1,998	44.4	0.70	0.96	0.82	229,200	120,600
GOA	silvergray rockfish	subadult	159	1.4	0.18	0.88	0.21	104,500	55,000
GOA	silvergray rockfish	adult	557	33.3	0.37	0.93	0.63	184,300	97,000
GOA	slender sole	all	751	5.0	0.44	0.94	0.68	127,100	66,900

Region	Species	Life stage	N	RMSE	*ρ*	AUC	PDE	EFH area	Core EFH area
GOA	southern rock sole	subadult	2,213	30.2	0.71	0.94	0.64	198,100	104,300
GOA	southern rock sole	adult	2,772	22.1	0.76	0.94	0.64	212,100	111,700
GOA	spiny dogfish	subadult	1,262	10.3	0.41	0.83	0.45	269,400	141,800
GOA	spiny dogfish	adult	127	0.29	0.15	0.86	0.35	55,400	29,100
GOA	starry flounder	early juvenile	61	--	--	0.98	--	63,800	33,600
GOA	starry flounder	subadult	68	0.80	0.19	0.98	0.65	23,100	12,200
GOA	starry flounder	adult	604	13.3	0.43	0.96	0.59	115,300	60,700
GOA	walleye pollock	early juvenile	2,958	--	--	0.82	--	254,200	133,800
GOA	walleye pollock	subadult	4,599	298	0.40	0.70	0.21	281,700	148,300
GOA	walleye pollock	adult	4,351	237	0.49	0.74	0.23	281,800	148,300
GOA	yelloweye rockfish	subadult	79	0.17	0.16	0.92	0.39	27,100	14,300
GOA	yelloweye rockfish	adult	186	0.46	0.22	0.91	0.43	64,500	33,900
GOA	yellowfin sole	early juvenile	66	--	--	0.98	--	54,600	28,700
GOA	yellowfin sole	subadult	401	46.9	0.38	0.98	0.78	101,600	53,500
GOA	yellowfin sole	adult	491	58.0	0.40	0.98	0.79	118,900	62,600

5.3 Appendix 3

5.3.1 EFH Comparisons 2017 and 2022

Appendix 3 provides EFH comparisons between the SDMs, EFH areas and subareas, EFH maps, and EFH Levels of the 2017 and 2022 EFH 5-year Reviews—

- Table A3.1 lists the EFH Levels from the 2017 EFH 5-year Review and the new EFH Levels available for the 2022 5-year Review, demonstrating EFH information level advancements.
- Table A3.2 provides a summary comparing SDM type, SDM performance, EFH area, and core EFH area between the SDMs produced for the 2017 and 2022 EFH 5-year Reviews.
- Overlay maps (e.g., species case studies results; Figure 13), demonstrating the area extent of the 2017 and 2022 EFH maps are provided as image files for each species life stage where comparisons were possible (Attachment 2). An example is provided in this section for adult walleye pollock in the Bering Sea (Figure A3.1).

5.3.1.1 Comparison of 2017 and 2022 EFH Levels

Updates to data and methods used during the 2022 EFH 5-year Review have resulted in advancements in the EFH Level for many species' life stages (Table A3.1). This information is provided as an outcome of an EFH 5-year Review (e.g., Simpson et al. 2017) and SSC requested a summary of EFH Level advancements in the 2022 EFH 5-year Review for their February 2022 review of EFH component 1 (Table A1.1 item 6e).

EFH Level 1 is applied to species' life stages with a model that predicts distribution or presence/absence. EFH Level 2 is applied to species' life stages with a model that can also predict abundance. EFH Level 3 is applied to species' life stages where a vital rate has been combined with a model to supplement either Level 1 or Level 2 predictions. **Compared to 2017, the 2022 5-year Review resulted in the following advancements:**

- Across all regions, 61 new species' life stages were modelled for the first time, and their EFH level was advanced from none to Level 2.
- In the GOA, the settled early juvenile life stages for 11 species were modelled for the first time and their EFH level was advanced from none to Level 1.
- Eight species' life stages where the settled early juvenile life stage was modelled for the first time are presented with additional EFH Level 3 information, advancing their EFH level to Level 3. Two of these species were based on Level 2 SDM ensembles for the AI and EBS, while six were based on Level 1 SDMs for the GOA that use combined survey data.
- Seven species' life stages were not updated, and the EFH Level 1 designation from 2017 is retained. These cases refer to species/life stages where fewer than 50 positive survey catches were available in 2022 (e.g., hauls where the species was present).
- In total, 55 species' life stages were advanced from EFH Level 1 to 2.
- Across all regions, 84 species' life stages were modelled as EFH Level 2 in both 2017 and 2022, although the data and methods were updated and revised in the 2022 SDM ensemble approach to mapping EFH.
- For the first time, EFH Level 2 models were combined for member species of each of 7 stock complexes in the BSAI (4) and GOA (3) groundfish FMPs to represent the EFH of member species where a model was not possible (i.e., fewer than 50 positive survey catches were available).

Table A3.1. Comparison of the EFH information levels accomplished from SDMs produced for the 2017 and 2022 EFH 5-year Reviews for species' life stages modeled in each region with model type, 2017 EFH Level, and the new 2022 EFH Level, demonstrating EFH information level advancements available for the 2022 EFH 5-year Review.

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
AI	Alaska skate	subadult	MaxEnt	1	ensemble	2
AI	Alaska skate	adult	MaxEnt	1	ensemble	2
AI	Aleutian skate	subadult	MaxEnt	1	ensemble	2
AI	Aleutian skate	adult	MaxEnt	1	ensemble	2
AI	arrowtooth flounder	early juvenile	--	0	ensemble	2
AI	arrowtooth flounder	subadult	GAM	2	ensemble	2
AI	arrowtooth flounder	adult	GAM	2	ensemble	2
AI	Atka mackerel	subadult	hGAM	2	ensemble	2
AI	Atka mackerel	adult	GAM	2	ensemble	2
AI	Bering skate	subadult	MaxEnt	1	--	1
AI	Bering skate	adult	MaxEnt	1	--	1
AI	Dover sole	subadult	MaxEnt	1	ensemble	2
AI	Dover sole	adult	MaxEnt	1	ensemble	2
AI	dusky rockfish	subadult	MaxEnt	1	ensemble	2
AI	dusky rockfish	adult	MaxEnt	1	ensemble	2
AI	English sole	adult	--	0	ensemble	2
AI	flathead sole	early juvenile	--	0	ensemble	2
AI	flathead sole	subadult	hGAM	2	ensemble	2
AI	flathead sole	adult	hGAM	2	ensemble	2
AI	giant octopus	all	hGAM	2	ensemble	2
AI	golden king crab	all	hGAM	2	ensemble	2
AI	Greenland turbot	subadult	MaxEnt	1	--	1
AI	Greenland turbot	adult	MaxEnt	1	ensemble	2
AI	harlequin rockfish	subadult	MaxEnt	1	--	1
AI	harlequin rockfish	adult	MaxEnt	1	ensemble	2
AI	Kamchatka flounder	subadult	GAM	2	ensemble	2
AI	Kamchatka flounder	adult	hGAM	2	ensemble	2
AI	mud skate	subadult	hGAM	2	ensemble	2
AI	mud skate	adult	MaxEnt	1	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
AI	northern rock sole	early juvenile	--	0	ensemble	2
AI	northern rock sole	subadult	GAM	2	ensemble	2
AI	northern rock sole	adult	GAM	2	ensemble	2
AI	northern rockfish	subadult	MaxEnt	1	ensemble	2
AI	northern rockfish	adult	GAM	2	ensemble	2
AI	Pacific cod	subadult	GAM	2	ensemble	2
AI	Pacific cod	adult	GAM	2	ensemble	2
AI	Pacific ocean perch	early juvenile	--	0	ensemble	2
AI	Pacific ocean perch	subadult	hGAM	2	ensemble	2
AI	Pacific ocean perch	adult	GAM	2	ensemble	2
AI	red king crab	all	--	0	ensemble	2
AI	rex sole	subadult	hGAM	2	ensemble	2
AI	rex sole	adult	GAM	2	ensemble	2
AI	rougheye blackspotted complex	subadult	--	0	ensemble	2
AI	rougheye blackspotted complex	adult	--	0	ensemble	2
AI	sablefish	subadult	MaxEnt	1	ensemble	2
AI	sablefish	adult	MaxEnt	1	ensemble	2
AI	shortraker rockfish	subadult	MaxEnt	1	ensemble	2
AI	shortraker rockfish	adult	hGAM	2	ensemble	2
AI	shortspine thornyhead	subadult	MaxEnt	1	ensemble	2
AI	shortspine thornyhead	adult	hGAM	2	ensemble	2
AI	southern rock sole	subadult	MaxEnt	1	ensemble	2
AI	southern rock sole	adult	MaxEnt	1	ensemble	2
AI	walleye pollock	early juvenile	--	0	ensemble	3
AI	walleye pollock	subadult	hGAM	2	ensemble	2
AI	walleye pollock	adult	GAM	2	ensemble	2
AI	whiteblotched skate	subadult	--	0	ensemble	2
AI	whiteblotched skate	adult	--	0	ensemble	2
EBS	Alaska plaice	early juvenile	--	0	ensemble	2
EBS	Alaska plaice	subadult	--	0	ensemble	2
EBS	Alaska plaice	adult	GAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
EBS	Alaska skate	subadult	GAM	2	ensemble	2
EBS	Alaska skate	adult	hGAM	2	ensemble	2
EBS	Aleutian skate	subadult	hGAM	2	ensemble	2
EBS	Aleutian skate	adult	MaxEnt	1	ensemble	2
EBS	arrowtooth flounder	early juvenile	--	0	ensemble	2
EBS	arrowtooth flounder	subadult	GAM	2	ensemble	2
EBS	arrowtooth flounder	adult	GAM	2	ensemble	2
EBS	Atka mackerel	adult	MaxEnt	1	ensemble	2
EBS	Bering skate	subadult	hGAM	2	ensemble	2
EBS	Bering skate	adult	hGAM	2	ensemble	2
EBS	Bering flounder	subadult	--	0	ensemble	2
EBS	Bering flounder	adult	--	0	ensemble	2
EBS	big skate	subadult	--	0	ensemble	2
EBS	blue king crab	all	hGAM	2	ensemble	2
EBS	butter sole	all	--	0	ensemble	2
EBS	deepsea sole	all	--	0	ensemble	2
EBS	Dover sole	subadult	MaxEnt	1	ensemble	2
EBS	Dover sole	adult	MaxEnt	1	ensemble	2
EBS	dusky rockfish	adult	MaxEnt	1	--	1
EBS	flathead sole	early juvenile	--	0	ensemble	2
EBS	flathead sole	subadult	GAM	2	ensemble	2
EBS	flathead sole	adult	GAM	2	ensemble	2
EBS	giant octopus	all	MaxEnt	1	ensemble	2
EBS	Greenland turbot	subadult	hGAM	2	ensemble	2
EBS	Greenland turbot	adult	hGAM	2	ensemble	2
EBS	Kamchatka flounder	subadult	GAM	2	ensemble	2
EBS	Kamchatka flounder	adult	hGAM	2	ensemble	2
EBS	longhead dab	all	--	0	ensemble	2
EBS	mud skate	subadult	MaxEnt	1	ensemble	2
EBS	mud skate	adult	MaxEnt	1	ensemble	2
EBS	northern rock sole	early juvenile	--	0	ensemble	2
EBS	northern rock sole	subadult	GAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
EBS	northern rock sole	adult	GAM	2	ensemble	2
EBS	northern rockfish	adult	MaxEnt	1	ensemble	2
EBS	Pacific cod	early juvenile	--	0	ensemble	3
EBS	Pacific cod	subadult	GAM	2	ensemble	2
EBS	Pacific cod	adult	GAM	2	ensemble	2
EBS	Pacific ocean perch	early juvenile	--	0	ensemble	2
EBS	Pacific ocean perch	subadult	MaxEnt	1	ensemble	2
EBS	Pacific ocean perch	adult	MaxEnt	1	ensemble	2
EBS	red king crab	all	hGAM	2	ensemble	2
EBS	rex sole	early juvenile	--	0	ensemble	2
EBS	rex sole	subadult	hGAM	2	ensemble	2
EBS	rex sole	adult	hGAM	2	ensemble	2
EBS	rougheye blackspotted complex	subadult	--	0	ensemble	2
EBS	rougheye blackspotted complex	adult	--	0	ensemble	2
EBS	sablefish	early juvenile	--	0	ensemble	2
EBS	sablefish	subadult	MaxEnt	1	ensemble	2
EBS	sablefish	adult	MaxEnt	1	ensemble	2
EBS	Sakhalin sole	subadult	--	0	ensemble	2
EBS	Sakhalin sole	adult	--	0	ensemble	2
EBS	shortraker rockfish	subadult	MaxEnt	1	ensemble	2
EBS	shortraker rockfish	adult	MaxEnt	1	ensemble	2
EBS	shortspine thornyhead	subadult	MaxEnt	1	ensemble	2
EBS	shortspine thornyhead	adult	MaxEnt	1	ensemble	2
EBS	snow crab	all	GAM	2	ensemble	2
EBS	southern rock sole	subadult	MaxEnt	1	--	1
EBS	southern rock sole	adult	MaxEnt	1	--	1
EBS	starry flounder	subadult	--	0	ensemble	2
EBS	starry flounder	adult	--	0	ensemble	2
EBS	Tanner crab	all	GAM	2	ensemble	2
EBS	walleye pollock	early juvenile	--	0	ensemble	2
EBS	walleye pollock	subadult	GAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
EBS	walleye pollock	adult	GAM	2	ensemble	2
EBS	whiteblotched skate	subadult	--	0	ensemble	2
EBS	whiteblotched skate	adult	--	0	ensemble	2
EBS	yellowfin sole	early juvenile	--	0	ensemble	2
EBS	yellowfin sole	subadult	GAM	2	ensemble	2
EBS	yellowfin sole	adult	GAM	2	ensemble	2
GOA	Alaska plaice	subadult	--	0	ensemble	2
GOA	Alaska plaice	adult	hGAM	2	ensemble	2
GOA	Alaska skate	subadult	MaxEnt	1	ensemble	2
GOA	Alaska skate	adult	MaxEnt	1	ensemble	2
GOA	Aleutian skate	subadult	hGAM	2	ensemble	2
GOA	Aleutian skate	adult	MaxEnt	1	ensemble	2
GOA	arrowtooth flounder	early juvenile	--	0	MaxEnt	1
GOA	arrowtooth flounder	subadult	GAM	2	ensemble	2
GOA	arrowtooth flounder	adult	GAM	2	ensemble	2
GOA	Atka mackerel	subadult	--	0	ensemble	2
GOA	Atka mackerel	adult	--	0	ensemble	2
GOA	Atka mackerel	all	hGAM	2	--	--
GOA	Bering skate	subadult	MaxEnt	1	ensemble	2
GOA	Bering skate	adult	MaxEnt	1	ensemble	2
GOA	big skate	subadult	--	0	ensemble	2
GOA	big skate	adult	--	0	ensemble	2
GOA	butter sole	subadult/adult	--	0	ensemble	2
GOA	Dover sole	subadult	GAM	2	ensemble	2
GOA	Dover sole	adult	GAM	2	ensemble	2
GOA	dusky rockfish	subadult	MaxEnt	1	ensemble	2
GOA	dusky rockfish	adult	hGAM	2	ensemble	2
GOA	English sole	early juvenile	--	0	MaxEnt	1
GOA	English sole	subadult	--	0	ensemble	2
GOA	English sole	adult	--	0	ensemble	2
GOA	flathead sole	early juvenile	--	0	MaxEnt	1
GOA	flathead sole	subadult	GAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
GOA	flathead sole	adult	GAM	2	ensemble	2
GOA	giant octopus	all	MaxEnt	1	ensemble	2
GOA	greenstriped rockfish	adult	--	0	ensemble	2
GOA	greenstriped rockfish	all	MaxEnt	1	--	--
GOA	harlequin rockfish	subadult	MaxEnt	1	ensemble	2
GOA	harlequin rockfish	adult	hGAM	2	ensemble	2
GOA	longnose skate	subadult	--	0	ensemble	2
GOA	longnose skate	adult	--	0	ensemble	2
GOA	northern/southern rock soles	early juvenile	--	0	MaxEnt	3
GOA	northern rock sole	subadult	hGAM	2	ensemble	2
GOA	northern rock sole	adult	hGAM	2	ensemble	2
GOA	northern rockfish	subadult	MaxEnt	1	ensemble	2
GOA	northern rockfish	adult	hGAM	2	ensemble	2
GOA	Pacific cod	early juvenile	--	0	MaxEnt	3
GOA	Pacific cod	subadult	GAM	2	ensemble	2
GOA	Pacific cod	adult	GAM	2	ensemble	2
GOA	Pacific ocean perch	early juvenile	--	0	MaxEnt	3
GOA	Pacific ocean perch	subadult	hGAM	2	ensemble	2
GOA	Pacific ocean perch	adult	GAM	2	ensemble	2
GOA	Pacific sanddab	all	--	0	ensemble	2
GOA	Petrale sole	subadult	--	0	ensemble	2
GOA	Petrale sole	adult	--	0	ensemble	2
GOA	pygmy rockfish	all	MaxEnt	1	ensemble	2
GOA	quillback rockfish	adult	--	0	ensemble	2
GOA	quillback rockfish	all	MaxEnt	1	--	--
GOA	redbanded rockfish	subadult	hGAM	2	ensemble	2
GOA	redbanded rockfish	adult	MaxEnt	1	ensemble	2
GOA	redstripe rockfish	subadult	MaxEnt	1	ensemble	2
GOA	redstripe rockfish	adult	MaxEnt	1	ensemble	2
GOA	rex sole	early juvenile	--	0	MaxEnt	1
GOA	rex sole	subadult	hGAM	2	ensemble	2

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
GOA	rex sole	adult	GAM	2	ensemble	2
GOA	rosethorn rockfish	subadult	MaxEnt	1	ensemble	2
GOA	rosethorn rockfish	adult	MaxEnt	1	ensemble	2
GOA	rougheye blackspotted complex	subadult	--	0	ensemble	2
GOA	rougheye blackspotted complex	adult	--	0	ensemble	2
GOA	sablefish	early juvenile	--	0	MaxEnt	3
GOA	sablefish	subadult	hGAM	2	ensemble	2
GOA	sablefish	adult	GAM	2	ensemble	2
GOA	sand sole	adult	--	0	ensemble	2
GOA	sharpchin rockfish	subadult	hGAM	2	ensemble	2
GOA	sharpchin rockfish	adult	MaxEnt	1	ensemble	2
GOA	shortraker rockfish	subadult	MaxEnt	1	ensemble	2
GOA	shortraker rockfish	adult	hGAM	2	ensemble	2
GOA	shortspine thornyhead	subadult	hGAM	2	ensemble	2
GOA	shortspine thornyhead	adult	hGAM	2	ensemble	2
GOA	silvergray rockfish	subadult	MaxEnt	1	ensemble	2
GOA	silvergray rockfish	adult	hGAM	2	ensemble	2
GOA	slender sole	all	--	0	ensemble	2
GOA	southern rock sole	subadult	hGAM	2	ensemble	2
GOA	southern rock sole	adult	GAM	2	ensemble	2
GOA	spiny dogfish	subadult	--	0	ensemble	2
GOA	spiny dogfish	adult	--	0	ensemble	2
GOA	starry flounder	early juvenile	--	0	MaxEnt	1
GOA	starry flounder	subadult	--	0	ensemble	2
GOA	starry flounder	adult	--	0	ensemble	2
GOA	walleye pollock	early juvenile	--	0	MaxEnt	3
GOA	walleye pollock	subadult	GAM	2	ensemble	2
GOA	walleye pollock	adult	GAM	2	ensemble	2
GOA	yelloweye rockfish	subadult	MaxEnt	1	ensemble	2
GOA	yelloweye rockfish	adult	MaxEnt	1	ensemble	2
GOA	yellowfin sole	early juvenile	--	0	MaxEnt	3

Region	Species	Life Stage	SDM 2017	EFH Level 2017	SDM 2022	EFH Level 2022
GOA	yellowfin sole	subadult	MaxEnt	1	ensemble	2
GOA	yellowfin sole	adult	hGAM	2	ensemble	2

5.3.1.2 *Comparison of 2017 and 2022 SDMs*

Table A3.2. Comparison of the SDMs produced for the 2017 and 2022 EFH 5-year Reviews. Model is the type of model used and is always "ensemble" when the year is 2022. Metrics shown are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE). EFH area (spatial domain containing the top 95% of occupied habitat) and core EFH area (EFH subarea containing the top 50% of occupied habitat; applied to the EFH fishing effects analysis in the 2017 EFH 5-year Review) are provided (km^2). The "--" sign indicates circumstances where a metric could not be calculated.

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Alaska skate	subadult	2017	MaxEnt	149	--	--	0.75	--	58,600	30,800
AI	Alaska skate	subadult	2022	ensemble	102	0.42	0.2	0.8	0.25	25,700	13,500
AI	Alaska skate	adult	2017	MaxEnt	289	--	--	0.75	--	52,200	27,500
AI	Alaska skate	adult	2022	ensemble	149	0.65	0.25	0.82	0.27	48,600	25,600
AI	Aleutian skate	subadult	2017	MaxEnt	273	--	--	0.67	--	68,900	36,300
AI	Aleutian skate	subadult	2022	ensemble	367	0.61	0.26	0.76	0.19	56,000	29,500
AI	Aleutian skate	adult	2017	MaxEnt	173	--	--	0.73	--	59,200	31,200
AI	Aleutian skate	adult	2022	ensemble	221	0.35	0.21	0.76	0.18	23,400	12,300
AI	arrowtooth flounder	subadult	2017	GAM	2,182	52.5	0.61	0.8	0.07	68,900	36,300
AI	arrowtooth flounder	subadult	2022	ensemble	3,503	84.5	0.63	0.79	0.4	77,700	40,900
AI	arrowtooth flounder	adult	2017	GAM	2,805	90.9	0.57	0.81	-0.14	76,300	40,200
AI	arrowtooth flounder	adult	2022	ensemble	3,118	42.9	0.49	0.75	0.29	77,700	40,900
AI	Atka mackerel	subadult	2017	hGAM	575	789	0.53	0.89	-0.51	22,400	11,800
AI	Atka mackerel	subadult	2022	ensemble	1,312	1,131	0.54	0.73	0.38	77,700	40,900
AI	Atka mackerel	adult	2017	GAM	1,672	1,880	0.48	0.74	-0.6	71,700	37,700

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Atka mackerel	adult	2022	ensemble	2,030	1,190	0.52	0.65	0.36	77,700	40,900
AI	Dover sole	subadult	2017	MaxEnt	280	--	--	0.77	--	56,700	29,800
AI	Dover sole	subadult	2022	ensemble	396	1.5	0.3	0.83	0.35	44,900	23,600
AI	Dover sole	adult	2017	MaxEnt	252	--	--	0.81	--	54,900	28,900
AI	Dover sole	adult	2022	ensemble	232	0.87	0.27	0.88	0.43	29,200	15,400
AI	dusky rockfish	subadult	2017	MaxEnt	32	--	--	0.92	--	37,200	19,600
AI	dusky rockfish	subadult	2022	ensemble	108	1.4	0.2	0.88	0.32	36,800	19,400
AI	dusky rockfish	adult	2017	MaxEnt	293	--	--	0.73	--	65,900	34,700
AI	dusky rockfish	adult	2022	ensemble	380	9.2	0.27	0.78	0.45	64,700	34,100
AI	flathead sole	subadult	2017	hGAM	685	87.7	0.58	0.9	0.15	19,800	10,400
AI	flathead sole	subadult	2022	ensemble	1,279	72.8	0.6	0.89	0.72	69,400	36,500
AI	flathead sole	adult	2017	hGAM	1,188	30.5	0.65	0.87	0.1	21,500	11,300
AI	flathead sole	adult	2022	ensemble	1,374	13.5	0.56	0.86	0.48	67,800	35,700
AI	giant octopus	all	2017	hGAM	504	1.2	0.13	0.63	-2.32	19,400	10,200
AI	giant octopus	all	2022	ensemble	682	0.81	0.2	0.67	0.09	72,000	37,900
AI	golden king crab	all	2017	hGAM	908	6.5	0.57	0.88	-0.29	26,400	13,900
AI	golden king crab	all	2022	ensemble	1,148	6.1	0.56	0.89	0.48	51,400	27,100
AI	Greenland turbot	adult	2017	MaxEnt	320	--	--	0.93	--	27,400	14,400
AI	Greenland turbot	adult	2022	ensemble	359	11.6	0.41	0.96	0.7	26,600	14,000

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	harlequin rockfish	adult	2017	MaxEnt	82	--	--	0.77	--	52,900	27,800
AI	harlequin rockfish	adult	2022	ensemble	111	23.4	0.18	0.86	0.39	62,000	32,600
AI	Kamchatka flounder	subadult	2017	GAM	1,649	23.9	0.53	0.79	-0.65	69,100	36,400
AI	Kamchatka flounder	subadult	2022	ensemble	2,207	22.6	0.58	0.81	0.51	77,600	40,900
AI	Kamchatka flounder	adult	2017	hGAM	814	33.3	0.58	0.89	0.45	26,900	14,200
AI	Kamchatka flounder	adult	2022	ensemble	918	19.4	0.54	0.9	0.75	51,800	27,300
AI	mud skate	subadult	2017	hGAM	422	2.8	0.49	0.87	0.18	23,200	12,200
AI	mud skate	subadult	2022	ensemble	488	2.1	0.46	0.9	0.63	34,200	18,000
AI	mud skate	adult	2017	MaxEnt	130	--	--	0.74	--	52,700	27,700
AI	mud skate	adult	2022	ensemble	290	0.41	0.28	0.82	0.26	36,600	19,200
AI	northern rock sole	subadult	2017	GAM	1,487	55.8	0.7	0.88	0.02	63,900	33,600
AI	northern rock sole	subadult	2022	ensemble	1,901	42.3	0.73	0.9	0.62	69,500	36,600
AI	northern rock sole	adult	2017	GAM	2,277	71.4	0.69	0.89	-0.02	68,800	36,200
AI	northern rock sole	adult	2022	ensemble	2,923	58.8	0.72	0.88	0.47	74,700	39,300
AI	northern rockfish	subadult	2017	MaxEnt	375	--	--	0.82	--	51,300	27,000
AI	northern rockfish	subadult	2022	ensemble	832	271	0.43	0.82	0.5	75,200	39,600
AI	northern rockfish	adult	2017	GAM	1,529	958	0.43	0.71	-0.28	69,000	36,300
AI	northern rockfish	adult	2022	ensemble	2,063	779	0.56	0.67	0.42	77,700	40,900
AI	Pacific cod	subadult	2017	GAM	1,194	37.4	0.42	0.75	-0.45	68,600	36,100

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	Pacific cod	subadult	2022	ensemble	2,872	34.1	0.47	0.74	0.28	74,100	39,000
AI	Pacific cod	adult	2017	GAM	2,567	56.3	0.49	0.76	-0.19	75,200	39,600
AI	Pacific cod	adult	2022	ensemble	3,084	40.4	0.5	0.76	0.37	77,600	40,800
AI	Pacific ocean perch	subadult	2017	hGAM	938	241	0.33	0.73	-0.22	18,500	9,800
AI	Pacific ocean perch	subadult	2022	ensemble	1,016	175	0.4	0.78	0.39	77,500	40,800
AI	Pacific ocean perch	adult	2017	GAM	2,158	1,765	0.68	0.82	-0.06	56,200	29,600
AI	Pacific ocean perch	adult	2022	ensemble	2,908	1,568	0.71	0.68	0.46	77,700	40,900
AI	rex sole	subadult	2017	hGAM	265	2.5	0.27	0.81	-0.19	18,200	9,600
AI	rex sole	subadult	2022	ensemble	1,145	8.1	0.48	0.83	0.47	68,900	36,300
AI	rex sole	adult	2017	GAM	1,525	28.7	0.52	0.8	-0.3	66,900	35,200
AI	rex sole	adult	2022	ensemble	1,891	22.6	0.56	0.82	0.43	77,200	40,600
AI	sablefish	subadult	2017	MaxEnt	18	--	--	0.9	--	19,900	10,400
AI	sablefish	subadult	2022	ensemble	472	9.7	0.43	0.93	0.54	41,400	21,800
AI	sablefish	adult	2017	MaxEnt	439	--	--	0.91	--	38,200	20,100
AI	sablefish	adult	2022	ensemble	368	8.1	0.4	0.95	0.66	33,100	17,400
AI	shortraker rockfish	subadult	2017	MaxEnt	286	--	--	0.96	--	21,900	11,500
AI	shortraker rockfish	subadult	2022	ensemble	408	8.5	0.47	0.98	0.86	23,300	12,200
AI	shortraker rockfish	adult	2017	hGAM	467	15.0	0.69	0.96	0.53	21,400	11,300
AI	shortraker rockfish	adult	2022	ensemble	514	6.1	0.48	0.96	0.76	27,400	14,400

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
AI	shortspine thornyhead	subadult	2017	MaxEnt	306	--	--	0.96	--	22,800	12,000
AI	shortspine thornyhead	subadult	2022	ensemble	380	8.1	0.46	0.98	0.76	23,200	12,200
AI	shortspine thornyhead	adult	2017	hGAM	745	28.8	0.72	0.95	0.54	21,300	11,200
AI	shortspine thornyhead	adult	2022	ensemble	1,051	26.1	0.61	0.93	0.74	54,800	28,900
AI	southern rock sole	subadult	2017	MaxEnt	395	--	--	0.96	--	34,100	17,900
AI	southern rock sole	subadult	2022	ensemble	583	12.9	0.55	0.97	0.73	41,600	21,900
AI	southern rock sole	adult	2017	MaxEnt	616	--	--	0.95	--	47,700	25,100
AI	southern rock sole	adult	2022	ensemble	763	11.0	0.62	0.97	0.81	42,300	22,200
AI	walleye pollock	subadult	2017	hGAM	794	341	0.34	0.78	-0.06	30,300	16,000
AI	walleye pollock	subadult	2022	ensemble	1,525	324	0.41	0.75	0.4	77,700	40,900
AI	walleye pollock	adult	2017	GAM	2,173	488	0.52	0.76	-0.44	66,800	35,200
AI	walleye pollock	adult	2022	ensemble	2,773	447	0.5	0.71	0.28	77,700	40,900
EBS	Alaska plaice	adult	2017	GAM	6,982	150	0.79	0.91	0.37	610,900	321,500
EBS	Alaska plaice	adult	2022	ensemble	8,684	111	0.81	0.92	0.56	660,400	347,600
EBS	Alaska skate	subadult	2017	GAM	4,845	10.9	0.63	0.84	-0.03	651,800	342,700
EBS	Alaska skate	subadult	2022	ensemble	6,801	10.1	0.63	0.86	0.32	676,100	355,800
EBS	Alaska skate	adult	2017	hGAM	3,634	6.0	0.47	0.76	-1.13	324,000	170,500
EBS	Alaska skate	adult	2022	ensemble	5,162	5.0	0.55	0.78	0.29	673,700	354,600
EBS	Aleutian skate	subadult	2017	hGAM	773	3.7	0.8	0.98	0.7	42,100	22,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	Aleutian skate	subadult	2022	ensemble	1,021	3.6	0.55	0.98	0.76	158,500	83,400
EBS	Aleutian skate	adult	2017	MaxEnt	150	--	--	0.97	--	62,300	32,800
EBS	Aleutian skate	adult	2022	ensemble	207	0.44	0.3	0.96	0.57	59,000	31,000
EBS	arrowtooth flounder	subadult	2017	GAM	3,357	95.9	0.75	0.92	0.43	505,800	265,900
EBS	arrowtooth flounder	subadult	2022	ensemble	5,669	119	0.84	0.95	0.69	524,200	275,900
EBS	arrowtooth flounder	adult	2017	GAM	4,149	83.9	0.82	0.95	0.45	504,500	265,500
EBS	arrowtooth flounder	adult	2022	ensemble	4,976	26.6	0.81	0.96	0.64	426,400	224,400
EBS	Atka mackerel	adult	2017	MaxEnt	57	--	--	0.88	--	296,200	155,400
EBS	Atka mackerel	adult	2022	ensemble	72	0.69	0.09	0.85	0.28	26,200	13,800
EBS	Bering skate	subadult	2017	hGAM	962	2.3	0.61	0.93	0.19	110,500	58,200
EBS	Bering skate	subadult	2022	ensemble	1,232	2.0	0.52	0.93	0.6	240,300	126,400
EBS	Bering skate	adult	2017	hGAM	1,045	1.0	0.54	0.9	-0.18	136,400	71,800
EBS	Bering skate	adult	2022	ensemble	1,429	0.88	0.51	0.9	0.48	267,300	140,700
EBS	blue king crab	all	2017	hGAM	1,373	8.5	0.62	0.94	0.52	109,400	57,600
EBS	blue king crab	all	2022	ensemble	1,650	8.0	0.47	0.93	0.52	472,600	248,700
EBS	Dover sole	subadult	2017	MaxEnt	109	--	--	0.93	--	170,400	89,700
EBS	Dover sole	subadult	2022	ensemble	182	0.45	0.21	0.96	0.57	45,500	23,900
EBS	Dover sole	adult	2017	MaxEnt	114	--	--	0.99	--	30,700	16,100
EBS	Dover sole	adult	2022	ensemble	91	0.37	0.3	0.99	0.73	13,200	7,000

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	flathead sole	subadult	2017	GAM	6,386	142	0.75	0.89	0.34	471,900	248,400
EBS	flathead sole	subadult	2022	ensemble	9,501	186	0.83	0.9	0.66	680,900	358,300
EBS	flathead sole	adult	2017	GAM	8,351	251	0.79	0.89	0.26	477,000	251,200
EBS	flathead sole	adult	2022	ensemble	9,702	143	0.71	0.88	0.33	681,800	358,900
EBS	giant octopus	all	2017	MaxEnt	492	--	--	0.87	--	335,100	176,000
EBS	giant octopus	all	2022	ensemble	693	0.69	0.28	0.88	0.31	207,500	109,200
EBS	Greenland turbot	subadult	2017	hGAM	2,370	11.5	0.63	0.92	0.31	158,100	83,200
EBS	Greenland turbot	subadult	2022	ensemble	2,419	10.2	0.55	0.93	0.58	392,300	206,500
EBS	Greenland turbot	adult	2017	hGAM	1,395	4.0	0.65	0.95	0.51	97,100	51,100
EBS	Greenland turbot	adult	2022	ensemble	1,974	4.2	0.53	0.95	0.7	241,800	127,300
EBS	Kamchatka flounder	subadult	2017	GAM	3,614	25.8	0.76	0.94	0.29	510,100	268,300
EBS	Kamchatka flounder	subadult	2022	ensemble	5,055	23.4	0.77	0.94	0.55	443,700	233,500
EBS	Kamchatka flounder	adult	2017	hGAM	1,658	4.0	0.61	0.92	0.3	125,600	66,100
EBS	Kamchatka flounder	adult	2022	ensemble	1,752	2.1	0.51	0.91	0.63	276,300	145,400
EBS	mud skate	subadult	2017	MaxEnt	149	--	--	0.99	--	27,600	14,500
EBS	mud skate	subadult	2022	ensemble	169	0.52	0.31	0.98	0.84	24,600	12,900
EBS	mud skate	adult	2017	MaxEnt	93	--	--	0.97	--	65,600	34,400
EBS	mud skate	adult	2022	ensemble	147	0.43	0.28	0.98	0.69	25,700	13,500
EBS	northern rock sole	subadult	2017	GAM	4,232	790	0.8	0.89	0.48	553,100	290,800

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	northern rock sole	subadult	2022	ensemble	7,020	716	0.86	0.82	0.65	674,800	355,100
EBS	northern rock sole	adult	2017	GAM	6,005	824	0.84	0.91	0.52	624,700	328,900
EBS	northern rock sole	adult	2022	ensemble	7,790	472	0.82	0.89	0.49	672,800	354,100
EBS	northern rockfish	adult	2017	MaxEnt	66	--	--	0.95	--	107,500	56,400
EBS	northern rockfish	adult	2022	ensemble	89	9.1	0.15	0.97	0.71	83,800	44,100
EBS	Pacific cod	subadult	2017	GAM	9,218	127	0.64	0.82	0.02	608,500	320,400
EBS	Pacific cod	subadult	2022	ensemble	12,889	118	0.59	0.8	0.24	680,500	358,200
EBS	Pacific cod	adult	2017	GAM	10,203	51.0	0.47	0.82	-0.06	663,600	349,500
EBS	Pacific cod	adult	2022	ensemble	11,853	20.5	0.48	0.79	0.15	675,700	355,600
EBS	Pacific ocean perch	subadult	2017	MaxEnt	122	--	--	0.97	--	91,600	47,800
EBS	Pacific ocean perch	subadult	2022	ensemble	131	1.9	0.18	0.98	0.56	83,900	44,100
EBS	Pacific ocean perch	adult	2017	MaxEnt	447	--	--	0.99	--	77,600	41,200
EBS	Pacific ocean perch	adult	2022	ensemble	561	308	0.34	0.99	0.39	191,900	101,000
EBS	red king crab	all	2017	hGAM	2,696	80.9	0.75	0.95	0.36	189,500	99,700
EBS	red king crab	all	2022	ensemble	3,376	74.6	0.67	0.95	0.52	363,900	191,500
EBS	rex sole	subadult	2017	hGAM	677	2.5	0.45	0.93	0.11	85,200	44,800
EBS	rex sole	subadult	2022	ensemble	1,849	9.1	0.52	0.95	0.65	262,100	137,900
EBS	rex sole	adult	2017	hGAM	1,925	17.0	0.71	0.95	0.62	123,300	64,900
EBS	rex sole	adult	2022	ensemble	2,171	9.8	0.56	0.95	0.77	233,100	122,700

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	sablefish	subadult	2017	MaxEnt	34	--	--	0.89	--	313,100	164,800
EBS	sablefish	subadult	2022	ensemble	391	2.2	0.32	0.97	0.6	75,700	39,800
EBS	sablefish	adult	2017	MaxEnt	544	--	--	0.99	--	79,500	41,800
EBS	sablefish	adult	2022	ensemble	544	1.8	0.39	0.99	0.77	67,800	35,700
EBS	shortraker rockfish	subadult	2017	MaxEnt	75	--	--	0.99	--	20,500	10,800
EBS	shortraker rockfish	subadult	2022	ensemble	122	0.88	0.31	0.99	0.8	27,800	14,600
EBS	shortraker rockfish	adult	2017	MaxEnt	127	--	--	0.99	--	22,800	12,100
EBS	shortraker rockfish	adult	2022	ensemble	142	1.7	0.33	1	0.85	13,600	7,200
EBS	shortspine thornyhead	subadult	2017	MaxEnt	220	--	--	1	--	21,500	11,200
EBS	shortspine thornyhead	subadult	2022	ensemble	253	4.3	0.5	1	0.87	22,600	11,900
EBS	shortspine thornyhead	adult	2017	MaxEnt	567	--	--	1	--	30,500	16,300
EBS	shortspine thornyhead	adult	2022	ensemble	696	16.0	0.55	1	0.92	47,700	25,100
EBS	snow crab	all	2017	GAM	8,756	1,633	0.82	0.91	0.18	607,600	319,900
EBS	snow crab	all	2022	ensemble	10,628	1,932	0.84	0.85	0.41	688,900	362,600
EBS	Tanner crab	all	2017	GAM	7,528	152	0.78	0.93	0.02	476,900	251,000
EBS	Tanner crab	all	2022	ensemble	9,244	140	0.8	0.93	0.35	540,400	284,400
EBS	walleye pollock	subadult	2017	GAM	8,680	635	0.59	0.82	-0.33	646,600	340,400
EBS	walleye pollock	subadult	2022	ensemble	9,528	553	0.69	0.76	0.3	689,500	362,900
EBS	walleye pollock	adult	2017	GAM	10,741	1,252	0.67	0.77	0.08	593,100	312,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
EBS	walleye pollock	adult	2022	ensemble	13,506	1,021	0.63	0.63	0.24	689,500	362,900
EBS	yellowfin sole	subadult	2017	GAM	6,808	820	0.89	0.96	0.59	582,100	306,400
EBS	yellowfin sole	subadult	2022	ensemble	9,289	977	0.9	0.95	0.63	617,900	325,200
EBS	yellowfin sole	adult	2017	GAM	7,724	744	0.88	0.96	0.59	594,100	312,700
EBS	yellowfin sole	adult	2022	ensemble	9,480	476	0.89	0.96	0.62	620,300	326,500
GOA	Alaska plaice	adult	2017	hGAM	325	3.9	0.53	0.97	0.44	40,600	21,400
GOA	Alaska plaice	adult	2022	ensemble	442	3.6	0.38	0.97	0.71	87,500	46,100
GOA	Alaska skate	subadult	2017	MaxEnt	72	--	--	0.71	--	317,700	167,100
GOA	Alaska skate	subadult	2022	ensemble	95	0.21	0.13	0.82	0.21	14,600	7,700
GOA	Alaska skate	adult	2017	MaxEnt	67	--	--	0.61	--	317,700	167,100
GOA	Alaska skate	adult	2022	ensemble	78	0.15	0.13	0.85	0.25	13,300	7,000
GOA	Aleutian skate	subadult	2017	hGAM	418	0.81	0.3	0.79	-0.89	71,600	37,700
GOA	Aleutian skate	subadult	2022	ensemble	613	0.54	0.28	0.78	0.3	165,800	87,300
GOA	Aleutian skate	adult	2017	MaxEnt	119	--	--	0.81	--	317,700	167,200
GOA	Aleutian skate	adult	2022	ensemble	147	0.19	0.17	0.83	0.25	30,600	16,100
GOA	arrowtooth flounder	subadult	2017	GAM	4,929	155	0.56	0.81	-0.14	295,900	155,700
GOA	arrowtooth flounder	subadult	2022	ensemble	7,390	276	0.64	0.7	0.28	281,800	148,300
GOA	arrowtooth flounder	adult	2017	GAM	5,583	376	0.6	0.84	-0.14	302,700	159,300
GOA	arrowtooth flounder	adult	2022	ensemble	7,043	189	0.55	0.76	0.29	281,800	148,300

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	Bering skate	subadult	2017	MaxEnt	313	--	--	0.83	--	317,700	167,300
GOA	Bering skate	subadult	2022	ensemble	401	0.33	0.27	0.84	0.28	113,600	59,800
GOA	Bering skate	adult	2017	MaxEnt	319	--	--	0.79	--	317,700	167,100
GOA	Bering skate	adult	2022	ensemble	407	0.32	0.28	0.84	0.31	94,700	49,800
GOA	Dover sole	subadult	2017	GAM	2,396	12.4	0.53	0.8	-0.3	281,100	148,000
GOA	Dover sole	subadult	2022	ensemble	3,710	17.4	0.62	0.83	0.46	281,300	148,000
GOA	Dover sole	adult	2017	GAM	2,685	21.6	0.67	0.87	-0.02	263,800	138,900
GOA	Dover sole	adult	2022	ensemble	2,973	11.0	0.62	0.87	0.42	272,900	143,600
GOA	dusky rockfish	subadult	2017	MaxEnt	100	--	--	0.82	--	317,700	167,000
GOA	dusky rockfish	subadult	2022	ensemble	315	17.7	0.21	0.8	0.27	235,200	123,800
GOA	dusky rockfish	adult	2017	hGAM	783	67.7	0.37	0.81	-0.78	74,200	39,100
GOA	dusky rockfish	adult	2022	ensemble	1,061	53.1	0.4	0.83	0.28	264,000	138,900
GOA	flathead sole	subadult	2017	GAM	2,556	104	0.55	0.8	-0.25	262,200	138,000
GOA	flathead sole	subadult	2022	ensemble	4,064	109	0.71	0.86	0.65	257,900	135,700
GOA	flathead sole	adult	2017	GAM	3,313	125	0.65	0.84	-0.14	274,900	144,700
GOA	flathead sole	adult	2022	ensemble	4,201	63.3	0.72	0.88	0.54	257,900	135,700
GOA	giant octopus	all	2017	MaxEnt	286	--	--	0.75	--	317,700	167,100
GOA	giant octopus	all	2022	ensemble	459	0.33	0.2	0.75	0.15	134,900	71,000
GOA	harlequin rockfish	subadult	2017	MaxEnt	221	--	--	0.86	--	317,600	167,200

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	harlequin rockfish	subadult	2022	ensemble	102	14.6	0.16	0.92	0.5	170,600	89,800
GOA	harlequin rockfish	adult	2017	hGAM	344	70.0	0.29	0.86	0.05	64,600	34,000
GOA	harlequin rockfish	adult	2022	ensemble	514	71.3	0.31	0.88	0.44	254,800	134,100
GOA	northern rock sole	subadult	2017	hGAM	1,319	52.7	0.76	0.95	0.52	77,900	41,000
GOA	northern rock sole	subadult	2022	ensemble	1,854	57.3	0.68	0.96	0.68	182,200	95,900
GOA	northern rock sole	adult	2017	hGAM	1,546	28.3	0.78	0.95	0.45	88,500	46,600
GOA	northern rock sole	adult	2022	ensemble	1,980	25.0	0.68	0.95	0.58	190,700	100,400
GOA	northern rockfish	subadult	2017	MaxEnt	203	--	--	0.85	--	317,700	167,100
GOA	northern rockfish	subadult	2022	ensemble	522	8.3	0.3	0.86	0.42	215,600	113,500
GOA	northern rockfish	adult	2017	hGAM	942	318	0.51	0.88	0.11	56,600	29,800
GOA	northern rockfish	adult	2022	ensemble	1,141	276	0.46	0.89	0.32	261,100	137,400
GOA	Pacific cod	subadult	2017	GAM	1,947	143	0.52	0.81	-0.3	260,200	136,900
GOA	Pacific cod	subadult	2022	ensemble	3,653	66.2	0.53	0.79	0.3	265,600	139,800
GOA	Pacific cod	adult	2017	GAM	3,615	97.9	0.48	0.76	-0.36	295,900	155,700
GOA	Pacific cod	adult	2022	ensemble	4,476	70.2	0.47	0.75	0.25	264,700	139,300
GOA	Pacific ocean perch	subadult	2017	hGAM	1,612	68.5	0.51	0.85	-0.08	100,100	52,700
GOA	Pacific ocean perch	subadult	2022	ensemble	1,686	48.6	0.49	0.85	0.39	253,400	133,400
GOA	Pacific ocean perch	adult	2017	GAM	2,129	700	0.61	0.86	-0.38	248,000	130,500
GOA	Pacific ocean perch	adult	2022	ensemble	2,992	692	0.65	0.81	0.39	281,500	148,100

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	pygmy rockfish	all	2017	MaxEnt	54	--	--	0.89	--	317,700	166,900
GOA	pygmy rockfish	all	2022	ensemble	63	3.0	0.14	0.96	0.4	74,900	39,400
GOA	redbanded rockfish	subadult	2017	hGAM	599	2.3	0.55	0.93	0.26	50,100	26,400
GOA	redbanded rockfish	subadult	2022	ensemble	829	2.1	0.46	0.94	0.63	116,600	61,400
GOA	redbanded rockfish	adult	2017	MaxEnt	223	--	--	0.92	--	317,700	167,200
GOA	redbanded rockfish	adult	2022	ensemble	321	1.6	0.29	0.93	0.49	98,800	52,000
GOA	redstripe rockfish	subadult	2017	MaxEnt	72	--	--	0.86	--	317,600	167,100
GOA	redstripe rockfish	subadult	2022	ensemble	133	7.2	0.2	0.95	0.52	95,400	50,200
GOA	redstripe rockfish	adult	2017	MaxEnt	163	--	--	0.91	--	317,700	167,100
GOA	redstripe rockfish	adult	2022	ensemble	234	47.9	0.25	0.94	0.65	214,500	112,900
GOA	rex sole	subadult	2017	hGAM	1,907	6.4	0.39	0.77	-0.94	127,100	66,900
GOA	rex sole	subadult	2022	ensemble	4,744	33.6	0.56	0.8	0.32	281,800	148,300
GOA	rex sole	adult	2017	GAM	3,962	64.6	0.57	0.82	-0.32	286,500	150,800
GOA	rex sole	adult	2022	ensemble	4,455	36.3	0.59	0.8	0.37	280,100	147,400
GOA	rosethorn rockfish	subadult	2017	MaxEnt	105	--	--	0.97	--	317,700	167,300
GOA	rosethorn rockfish	subadult	2022	ensemble	132	0.93	0.3	0.99	0.76	25,900	13,700
GOA	rosethorn rockfish	adult	2017	MaxEnt	141	--	--	0.97	--	317,600	167,200
GOA	rosethorn rockfish	adult	2022	ensemble	186	2.5	0.4	0.99	0.82	29,600	15,600
GOA	sablefish	subadult	2017	hGAM	463	4.5	0.31	0.84	-0.22	117,700	61,900

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	sablefish	subadult	2022	ensemble	2,812	47.0	0.56	0.84	0.34	278,400	146,500
GOA	sablefish	adult	2017	GAM	2,383	58.3	0.71	0.9	-0.13	245,300	129,100
GOA	sablefish	adult	2022	ensemble	2,011	18.9	0.65	0.94	0.61	216,700	114,100
GOA	sharpchin rockfish	subadult	2017	hGAM	405	59.7	0.47	0.93	0.43	56,600	29,800
GOA	sharpchin rockfish	subadult	2022	ensemble	498	47.0	0.37	0.96	0.69	191,800	100,900
GOA	sharpchin rockfish	adult	2017	MaxEnt	337	--	--	0.91	--	317,700	167,200
GOA	sharpchin rockfish	adult	2022	ensemble	425	97.9	0.34	0.95	0.54	218,600	115,100
GOA	shortraker rockfish	subadult	2017	MaxEnt	164	--	--	0.98	--	317,700	167,400
GOA	shortraker rockfish	subadult	2022	ensemble	316	1.4	0.45	0.99	0.77	24,800	13,000
GOA	shortraker rockfish	adult	2017	hGAM	526	9.3	0.67	0.97	0.65	36,000	19,000
GOA	shortraker rockfish	adult	2022	ensemble	679	7.6	0.47	0.97	0.73	65,200	34,300
GOA	shortspine thornyhead	subadult	2017	hGAM	1,258	27.3	0.84	0.98	0.71	66,500	35,000
GOA	shortspine thornyhead	subadult	2022	ensemble	1,634	24.4	0.65	0.97	0.76	186,900	98,400
GOA	shortspine thornyhead	adult	2017	hGAM	1,490	47.5	0.85	0.98	0.77	84,900	44,700
GOA	shortspine thornyhead	adult	2022	ensemble	1,998	44.4	0.7	0.96	0.82	229,200	120,600
GOA	silvergray rockfish	subadult	2017	MaxEnt	124	--	--	0.83	--	317,700	167,200
GOA	silvergray rockfish	subadult	2022	ensemble	159	1.4	0.18	0.88	0.21	104,500	55,000
GOA	silvergray rockfish	adult	2017	hGAM	384	40.7	0.45	0.94	0.29	63,500	33,400
GOA	silvergray rockfish	adult	2022	ensemble	557	33.3	0.37	0.93	0.63	184,300	97,000

Region	Species	Life stage	Year	Model	N	RMSE	ρ	AUC	PDE	EFH area	Core EFH area
GOA	southern rock sole	subadult	2017	hGAM	1,451	24.5	0.69	0.92	0.22	98,700	51,900
GOA	southern rock sole	subadult	2022	ensemble	2,213	30.2	0.71	0.94	0.65	198,100	104,300
GOA	southern rock sole	adult	2017	GAM	2,154	37.4	0.72	0.91	0.21	248,900	131,000
GOA	southern rock sole	adult	2022	ensemble	2,772	22.1	0.76	0.94	0.64	212,100	111,700
GOA	walleye pollock	subadult	2017	GAM	3,271	300	0.43	0.73	-0.68	301,200	158,500
GOA	walleye pollock	subadult	2022	ensemble	4,599	298	0.4	0.7	0.21	281,700	148,300
GOA	walleye pollock	adult	2017	GAM	3,259	259	0.55	0.8	-0.79	277,200	145,900
GOA	walleye pollock	adult	2022	ensemble	4,351	237	0.49	0.74	0.23	281,800	148,300
GOA	yelloweye rockfish	subadult	2017	MaxEnt	53	--	--	0.85	--	317,700	167,000
GOA	yelloweye rockfish	subadult	2022	ensemble	79	0.17	0.16	0.92	0.39	27,100	14,300
GOA	yelloweye rockfish	adult	2017	MaxEnt	142	--	--	0.86	--	317,600	167,200
GOA	yelloweye rockfish	adult	2022	ensemble	186	0.46	0.22	0.91	0.43	64,500	33,900
GOA	yellowfin sole	subadult	2017	MaxEnt	225	--	--	0.97	--	317,700	167,200
GOA	yellowfin sole	subadult	2022	ensemble	401	46.9	0.38	0.98	0.78	101,600	53,500
GOA	yellowfin sole	adult	2017	hGAM	367	88.7	0.62	0.97	0.61	35,000	18,400
GOA	yellowfin sole	adult	2022	ensemble	491	58.0	0.4	0.98	0.79	118,900	62,600

5.3.2 *Comparison of 2017 and 2022 EFH Areas*

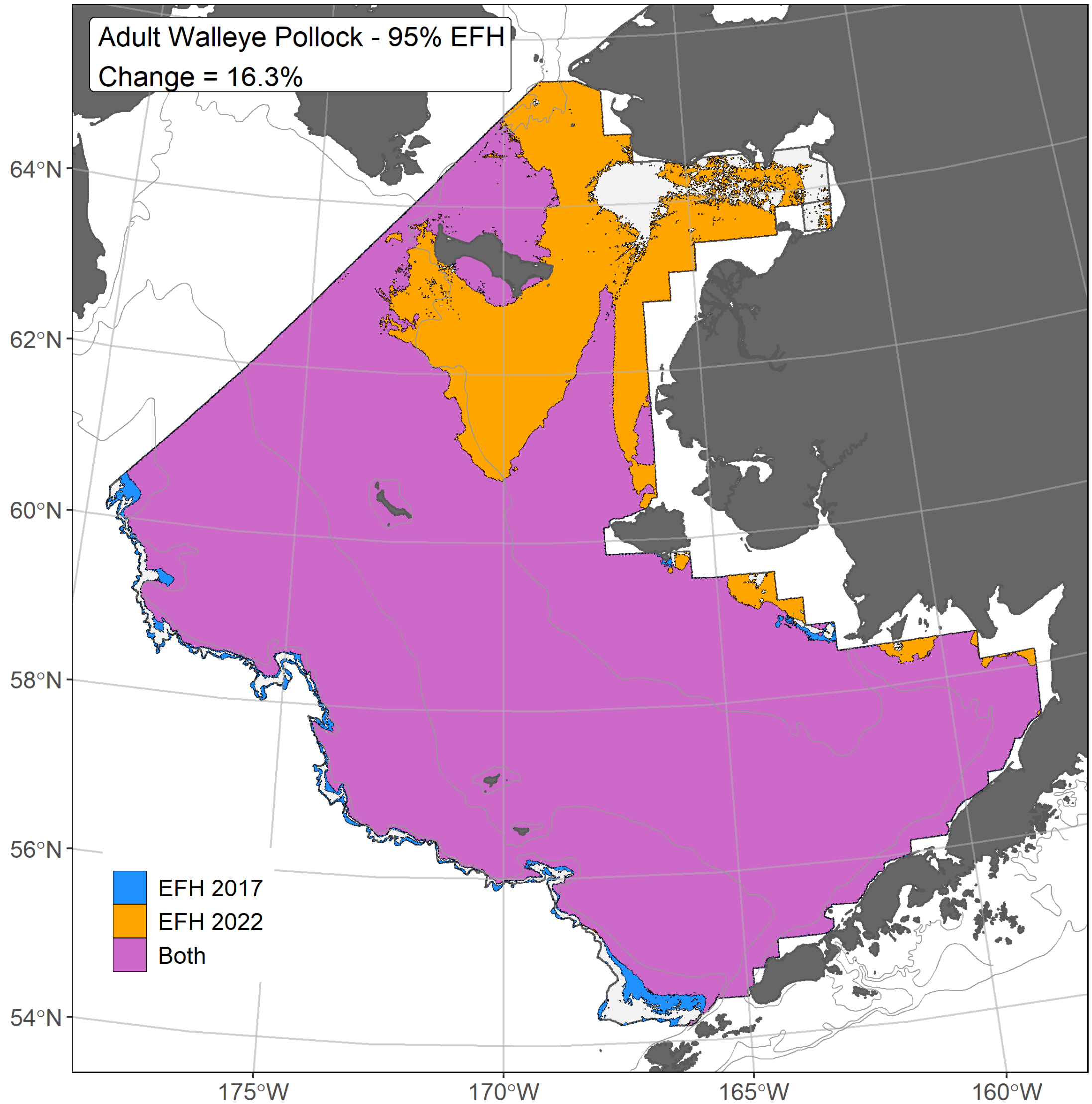

Figure A3.1. Change from 2017 to 2022 in essential fish habitat (EFH), which is the area containing the top 95% of occupied habitat (defined as encounter probabilities greater than 5%) from a habitat-based ensemble fitted from adult walleye pollock catches in AFSC RACE-GAP summer bottom trawl surveys (1992–2019) with 50 m, 100 m, and 200 m isobaths indicated. Colored areas represent EFH in 2017, 2022, or both (see Attachment 2 for additional species' life stage figures).

5.4 Appendix 4

5.4.1 2022 SDM Performance Metrics Current and Additional

Appendix 4 provides metrics chosen by the Laman et al. study to comprehensively report SDM performance for the 2022 EFH 5-year Review, additional metrics considered by this study, and additional metrics that the SSC requested for consideration at the October 2021 meeting—

- Table A4.1 provides metrics for the models (SDM or ensemble) produced for the 2022 EFH 5-year Review.
    - Metrics chosen by the Laman et al. study developing the SDMs for the 2022 EFH 5-year Review are the number of positive catches (N), the root mean square error (RMSE), Spearman's rank order correlation (ρ), the area under the receiver operating characteristic curve (AUC), and the Poisson deviance explained (PDE).
    - Additional metrics considered by the Laman et al. study were the prevalence of positive catches (Prev.), the Pearson correlation (*r*), and accuracy (Acc.).
    - Additional metrics that the SSC requested be considered in October 2021 are the area under the precision-recall receiver operating characteristic curve (PR-AUC) and the F_1 score (F_1) (Table A1.1 items 6j and 6k).
    - See the Synthesis section 3.3.3 of the Results.

The 2022 EFH 5-year Review used four metrics to assess the predictive skill of SDM ensembles. The RMSE is a measure of the variance in predictions relative to the observed data, and was used to weight the constituent SDMs for each species life stage. The RMSE is useful for comparing different models, though it does not provide information about fit on its own. Spearman's rank order correlation (ρ) is a measure of whether an SDM predicts the relative ordering of high or low values in the data, and is used to assess model fit. Area under the receiver operating characteristic curve (AUC) is a measure of discrimination ability and is used to assess the ability of a model to correctly predict presence or absence. The Poisson deviance explained (PDE) is a measure of fit that adjusts for the non-normal errors expected from count data and is used to assess the ability of a model to predict the observed abundance. See the Statistical Modeling section of the Methods in this document for additional details.

The four model performance metrics selected in this project and described above are only a small sample of the total number of statistical measures available for assessing model fit. Five additional metrics investigated to describe ensemble performance are presented in Appendix 4 Table A4.1. These provide additional nuance when interpreting the validity and fit of the ensembles. The first of these is prevalence (Prev.), the number of positive catches divided by the total number of valid hauls for that species. This metric provides further information about the relative commonness or scarcity of a species in the RACE-GAP bottom trawl surveys. The Pearson correlation (*r*) is a commonly used statistic that measures the degree to which model predictions match observed data. It was not used in the 2022 EFH 5-year Review because it assumes that the data follow a normal distribution; count data modeled here follow a Poisson distribution. The Pearson correlation can take on values between negative one and one; higher absolute values indicate a better fit. The Precision-Recall area under the receiver operating characteristic curve (PR-AUC) is a variation of the AUC that focuses on predictive skill for presence locations. Whereas AUC measures the rate of true positives compared to the rate of false positives, PR-AUC measures the degree of precision (true positives/predicted positives) compared to recall (true positive/observed positives). PR-AUC values range from zero to one, with higher values indicating better performance. The F_1 score (F_1),

$$F_1 = 2 * \frac{precision*recall}{precision+recall},$$

is similar to PR-AUC in that it is a measure of classification skill for presence or absence data with a focus on presence locations. The F_1 score also has a value between zero and one and is typically similar to the PR-AUC. Both PR-AUC and F_1 scores were requested by the SSC at the October 2021 meeting (Table A1.1 items 6j and 6k) and are reported here. The accuracy (Acc.) is the number of correct predictions divided by the total number of observations, and provides an easier to interpret metric that focuses equally on presence and absence in the data

Table A4.1. Performance metrics for the SDMs and ensembles produced for the 2022 EFH 5-year Review. Metrics shown are the number of positive catches (N), the prevalence of positive catches (Prev.), the root mean square error (RMSE), the Pearson correlation (*r*), Spearman's rank order correlation (*ρ*), the area under the receiver operating characteristic curve (AUC), the area under the precision-recall receiver operating characteristic curve (PR-AUC), the F_1 score (F_1), the accuracy (Acc.), and the Poisson deviance explained (PDE). The "--" sign indicates circumstances where a statistic could not be calculated, which occurs for some MaxEnt models for early juveniles in the GOA. Metrics chosen by the study developing the SDMs for the 2022 EFH 5-year Review are in bold text. Additional metrics considered by this study (Prev., *r*, Acc.) are in italics. Additional metrics that the SSC requested be considered in October 2021 (PR-AUC, F_1) are underlined.

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
AI	Alaska skate	subadult	102	0.04	0.42	0.27	0.20	0.80	0.24	0.17	0.74	0.25
AI	Alaska skate	adult	149	0.06	0.65	0.30	0.25	0.81	0.22	0.25	0.75	0.27
AI	Aleutian skate	subadult	367	0.09	0.61	0.28	0.26	0.76	0.26	0.29	0.71	0.19
AI	Aleutian skate	adult	221	0.05	0.35	0.29	0.21	0.76	0.18	0.19	0.71	0.18
AI	arrowtooth flounder	early juvenile	341	0.07	1.5	0.52	0.35	0.90	0.45	0.41	0.84	0.56
AI	arrowtooth flounder	subadult	3,503	0.70	84.5	0.44	0.63	0.79	0.88	0.84	0.75	0.40
AI	arrowtooth flounder	adult	3,118	0.62	42.9	0.31	0.49	0.75	0.81	0.78	0.72	0.29
AI	Atka mackerel	subadult	1,312	0.24	1,130	0.30	0.54	0.72	0.38	0.41	0.31	0.38
AI	Atka mackerel	adult	2,030	0.38	1,190	0.40	0.52	0.65	0.47	0.56	0.41	0.36
AI	Dover sole	subadult	396	0.07	1.5	0.29	0.30	0.83	0.31	0.31	0.76	0.35
AI	Dover sole	adult	232	0.04	0.87	0.41	0.27	0.88	0.32	0.26	0.80	0.43
AI	dusky rockfish	subadult	108	0.02	1.4	0.19	0.20	0.88	0.19	0.16	0.80	0.32
AI	dusky rockfish	adult	380	0.08	9.2	0.42	0.27	0.78	0.30	0.29	0.71	0.44
AI	English sole	adult	50	0.01	1.5	0.78	0.23	0.98	0.54	0.20	0.93	0.82
AI	flathead sole	early juvenile	183	0.03	5.5	0.73	0.28	0.94	0.55	0.27	0.84	0.81
AI	flathead sole	subadult	1,279	0.24	72.8	0.70	0.60	0.89	0.70	0.68	0.81	0.72

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
AI	flathead sole	adult	1,374	0.26	13.5	0.47	0.56	0.86	0.66	0.65	0.78	0.48
AI	giant octopus	all	682	0.13	0.81	0.17	0.20	0.67	0.21	0.29	0.62	0.09
AI	golden king crab	all	1,148	0.21	6.1	0.40	0.56	0.89	0.67	0.65	0.81	0.48
AI	Greenland turbot	adult	359	0.07	11.6	0.49	0.41	0.96	0.71	0.58	0.91	0.70
AI	harlequin rockfish	adult	111	0.02	23.4	0.18	0.18	0.86	0.13	0.13	0.78	0.40
AI	Kamchatka flounder	subadult	2,207	0.44	22.6	0.62	0.58	0.81	0.76	0.70	0.73	0.51
AI	Kamchatka flounder	adult	918	0.18	19.4	0.71	0.54	0.90	0.70	0.62	0.82	0.74
AI	mud skate	subadult	488	0.12	2.1	0.65	0.46	0.90	0.58	0.52	0.82	0.63
AI	mud skate	adult	290	0.07	0.41	0.35	0.28	0.82	0.25	0.28	0.74	0.26
AI	northern rock sole	early juvenile	154	0.03	0.57	0.33	0.25	0.89	0.29	0.21	0.80	0.38
AI	northern rock sole	subadult	1,901	0.41	42.3	0.59	0.73	0.90	0.86	0.80	0.82	0.62
AI	northern rock sole	adult	2,923	0.63	58.8	0.49	0.72	0.88	0.91	0.86	0.81	0.47
AI	northern rockfish	subadult	832	0.16	271	0.35	0.43	0.82	0.41	0.36	0.47	0.50
AI	northern rockfish	adult	2,063	0.39	779	0.42	0.56	0.68	0.50	0.58	0.44	0.42
AI	Pacific cod	subadult	2,872	0.54	34.1	0.30	0.47	0.74	0.71	0.76	0.71	0.28
AI	Pacific cod	adult	3,084	0.58	40.4	0.45	0.50	0.76	0.77	0.77	0.70	0.37
AI	Pacific ocean perch	early juvenile	722	0.14	68.8	0.34	0.36	0.80	0.37	0.40	0.67	0.38
AI	Pacific ocean perch	subadult	1,016	0.19	175	0.37	0.40	0.78	0.42	0.40	0.45	0.39
AI	Pacific ocean perch	adult	2,908	0.54	1,570	0.50	0.71	0.68	0.65	0.70	0.54	0.46
AI	red king crab	all	83	0.02	1.6	0.15	0.15	0.85	0.10	0.10	0.77	0.27

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
AI	rex sole	subadult	1,145	0.21	8.1	0.55	0.48	0.83	0.60	0.56	0.75	0.47
AI	rex sole	adult	1,891	0.35	22.6	0.46	0.56	0.82	0.71	0.67	0.74	0.43
AI	rougheye blackspotted complex	subadult	1,058	0.20	10.9	0.51	0.53	0.88	0.63	0.61	0.80	0.51
AI	rougheye blackspotted complex	adult	711	0.13	19.4	0.81	0.52	0.94	0.71	0.62	0.86	0.76
AI	sablefish	subadult	472	0.09	9.7	0.35	0.43	0.93	0.66	0.51	0.86	0.54
AI	sablefish	adult	368	0.07	8.1	0.78	0.40	0.95	0.56	0.50	0.88	0.66
AI	shortraker rockfish	subadult	408	0.08	8.5	0.82	0.47	0.98	0.85	0.68	0.93	0.86
AI	shortraker rockfish	adult	514	0.10	6.1	0.81	0.48	0.96	0.75	0.63	0.90	0.76
AI	shortspine thornyhead	subadult	380	0.07	8.1	0.55	0.46	0.98	0.83	0.64	0.93	0.76
AI	shortspine thornyhead	adult	1,051	0.20	26.1	0.74	0.61	0.93	0.80	0.70	0.85	0.74
AI	southern rock sole	subadult	583	0.13	12.9	0.56	0.55	0.97	0.82	0.75	0.92	0.73
AI	southern rock sole	adult	763	0.17	11.0	0.72	0.62	0.97	0.90	0.79	0.92	0.81
AI	walleye pollock	early juvenile	198	0.04	4.8	0.22	0.23	0.86	0.21	0.20	0.77	0.37
AI	walleye pollock	subadult	1,525	0.28	324	0.38	0.41	0.75	0.49	0.54	0.55	0.40
AI	walleye pollock	adult	2,773	0.52	447	0.30	0.50	0.71	0.66	0.68	0.52	0.28
AI	whiteblotched skate	subadult	459	0.11	2.5	0.61	0.48	0.94	0.62	0.60	0.87	0.66
AI	whiteblotched skate	adult	544	0.13	2.1	0.73	0.49	0.92	0.70	0.57	0.84	0.72
EBS	Alaska plaice	early juvenile	272	0.02	4.1	0.53	0.25	0.97	0.61	0.32	0.93	0.69
EBS	Alaska plaice	subadult	6,527	0.42	53.9	0.53	0.79	0.94	0.90	0.85	0.86	0.60

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
EBS	Alaska plaice	adult	8,684	0.56	111	0.54	0.81	0.92	0.91	0.84	0.80	0.56
EBS	Alaska skate	subadult	6,801	0.72	10.1	0.41	0.63	0.86	0.93	0.86	0.81	0.32
EBS	Alaska skate	adult	5,162	0.55	5.0	0.31	0.55	0.78	0.80	0.72	0.70	0.29
EBS	Aleutian skate	subadult	1,021	0.11	3.6	0.69	0.55	0.98	0.84	0.74	0.93	0.76
EBS	Aleutian skate	adult	207	0.02	0.44	0.35	0.30	0.96	0.30	0.33	0.92	0.57
EBS	arrowtooth flounder	early juvenile	1,975	0.16	8.6	0.44	0.56	0.93	0.69	0.67	0.86	0.55
EBS	arrowtooth flounder	subadult	5,669	0.47	119	0.65	0.84	0.95	0.93	0.88	0.88	0.69
EBS	arrowtooth flounder	adult	4,976	0.41	26.6	0.54	0.81	0.96	0.94	0.87	0.89	0.64
EBS	Atka mackerel	adult	72	0.00	0.69	0.08	0.09	0.85	0.05	0.02	0.71	0.28
EBS	Bering skate	subadult	1,232	0.13	2.0	0.58	0.52	0.93	0.66	0.62	0.86	0.60
EBS	Bering skate	adult	1,429	0.15	0.88	0.50	0.51	0.90	0.56	0.59	0.83	0.48
EBS	Bering sole	subadult	2,583	0.17	30.2	0.60	0.61	0.97	0.87	0.76	0.91	0.74
EBS	Bering sole	adult	2,966	0.19	29.6	0.46	0.64	0.96	0.85	0.78	0.90	0.67
EBS	big skate	subadult	62	0.00	0.11	0.57	0.17	0.96	0.35	0.09	0.94	0.58
EBS	blue king crab	all	1,650	0.11	8.0	0.35	0.47	0.93	0.70	0.57	0.86	0.52
EBS	butter sole	adult	177	0.01	13.7	0.32	0.20	0.98	0.34	0.24	0.93	0.60
EBS	deepsea sole	all	110	0.01	0.30	0.84	0.45	1.00	0.70	0.48	0.98	0.87
EBS	Dover sole	subadult	182	0.01	0.45	0.40	0.21	0.96	0.38	0.14	0.87	0.57
EBS	Dover sole	adult	91	0.01	0.37	0.47	0.30	0.99	0.48	0.33	0.98	0.73
EBS	flathead sole	early juvenile	4,794	0.31	36.6	0.35	0.60	0.86	0.72	0.67	0.77	0.44

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
EBS	flathead sole	subadult	9,501	0.61	186	0.66	0.83	0.90	0.90	0.86	0.81	0.66
EBS	flathead sole	adult	9,702	0.62	143	0.26	0.71	0.88	0.89	0.86	0.81	0.33
EBS	giant octopus	all	693	0.04	0.69	0.28	0.28	0.88	0.30	0.26	0.80	0.31
EBS	Greenland turbot	subadult	2,419	0.15	10.2	0.47	0.55	0.93	0.73	0.64	0.85	0.58
EBS	Greenland turbot	adult	1,974	0.13	4.2	0.50	0.53	0.95	0.77	0.66	0.88	0.70
EBS	Kamchatka flounder	subadult	5,055	0.42	23.4	0.46	0.77	0.94	0.92	0.85	0.87	0.55
EBS	Kamchatka flounder	adult	1,752	0.15	2.1	0.67	0.51	0.91	0.67	0.58	0.83	0.63
EBS	longhead dab	all	2,307	0.15	54.0	0.57	0.61	0.97	0.80	0.76	0.91	0.68
EBS	mud skate	subadult	169	0.02	0.52	0.90	0.31	0.98	0.72	0.39	0.95	0.83
EBS	mud skate	adult	147	0.02	0.43	0.49	0.28	0.98	0.54	0.30	0.93	0.69
EBS	northern rock sole	early juvenile	2,884	0.27	378	0.34	0.67	0.90	0.66	0.65	0.70	0.51
EBS	northern rock sole	subadult	7,020	0.67	716	0.66	0.86	0.82	0.85	0.86	0.78	0.65
EBS	northern rock sole	adult	7,790	0.74	472	0.44	0.82	0.89	0.93	0.91	0.85	0.49
EBS	northern rockfish	adult	89	0.01	9.1	0.40	0.15	0.97	0.35	0.11	0.92	0.71
EBS	Pacific cod	early juvenile	3,213	0.21	44.9	0.19	0.53	0.87	0.58	0.62	0.80	0.38
EBS	Pacific cod	subadult	12,889	0.83	118	0.29	0.58	0.80	0.93	0.93	0.88	0.24
EBS	Pacific cod	adult	11,853	0.76	20.5	0.21	0.48	0.79	0.91	0.88	0.81	0.15
EBS	Pacific ocean perch	early juvenile	95	0.01	1.2	0.28	0.17	0.97	0.23	0.11	0.91	0.59
EBS	Pacific ocean perch	subadult	131	0.01	1.9	0.29	0.18	0.98	0.23	0.17	0.92	0.56
EBS	Pacific ocean perch	adult	561	0.04	308	0.09	0.34	0.99	0.80	0.57	0.95	0.39

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
EBS	red king crab	all	3,376	0.22	74.6	0.21	0.67	0.95	0.84	0.73	0.86	0.52
EBS	rex sole	early juvenile	105	0.01	0.20	0.26	0.15	0.94	0.12	0.08	0.87	0.40
EBS	rex sole	subadult	1,849	0.12	9.1	0.50	0.52	0.95	0.71	0.66	0.89	0.65
EBS	rex sole	adult	2,171	0.14	9.8	0.75	0.56	0.95	0.76	0.69	0.89	0.77
EBS	rougheye blackspotted complex	subadult	208	0.01	0.82	0.80	0.28	0.99	0.63	0.32	0.95	0.78
EBS	rougheye blackspotted complex	adult	105	0.01	0.15	0.71	0.36	0.99	0.56	0.31	0.97	0.75
EBS	sablefish	early juvenile	59	0.00	0.21	0.19	0.12	0.94	0.10	0.06	0.91	0.37
EBS	sablefish	subadult	391	0.02	2.2	0.40	0.32	0.97	0.60	0.37	0.92	0.60
EBS	sablefish	adult	544	0.04	1.8	0.64	0.39	0.99	0.83	0.57	0.95	0.77
EBS	Sakhalin sole	subadult	476	0.03	16.5	0.32	0.29	0.98	0.65	0.44	0.93	0.63
EBS	Sakhalin sole	adult	225	0.01	2.1	0.47	0.22	0.97	0.48	0.23	0.91	0.68
EBS	shortraker rockfish	subadult	122	0.01	0.88	0.52	0.31	0.99	0.64	0.27	0.96	0.80
EBS	shortraker rockfish	adult	142	0.01	1.7	0.83	0.33	0.99	0.76	0.46	0.98	0.85
EBS	shortspine thornyhead	subadult	253	0.02	4.3	0.63	0.50	1.00	0.88	0.59	0.98	0.87
EBS	shortspine thornyhead	adult	696	0.04	16.0	0.80	0.55	1.00	0.93	0.83	0.98	0.92
EBS	snow crab	all	10,628	0.68	1,930	0.34	0.84	0.85	0.88	0.87	0.79	0.41
EBS	starry flounder	subadult	575	0.04	11.4	0.47	0.37	0.97	0.55	0.45	0.92	0.69
EBS	starry flounder	adult	1,619	0.10	19.2	0.33	0.51	0.96	0.69	0.66	0.90	0.58
EBS	Tanner crab	all	9,244	0.59	140	0.30	0.80	0.93	0.94	0.88	0.84	0.35

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
EBS	walleye pollock	early juvenile	9,367	0.60	463	0.11	0.55	0.75	0.76	0.79	0.68	0.14
EBS	walleye pollock	subadult	9,528	0.61	553	0.27	0.69	0.76	0.77	0.78	0.66	0.30
EBS	walleye pollock	adult	13,506	0.87	1,020	0.31	0.63	0.63	0.90	0.94	0.88	0.24
EBS	whiteblotched skate	subadult	224	0.02	1.8	0.45	0.34	0.99	0.62	0.46	0.95	0.72
EBS	whiteblotched skate	adult	201	0.02	0.34	0.59	0.33	0.98	0.60	0.42	0.94	0.69
EBS	yellowfin sole	early juvenile	2,134	0.14	191	0.40	0.57	0.97	0.78	0.70	0.89	0.65
EBS	yellowfin sole	subadult	9,289	0.60	977	0.54	0.90	0.95	0.93	0.91	0.88	0.63
EBS	yellowfin sole	adult	9,480	0.61	476	0.54	0.89	0.96	0.95	0.92	0.89	0.62
GOA	Alaska plaice	subadult	85	0.01	0.83	0.34	0.23	0.98	0.44	0.22	0.94	0.62
GOA	Alaska plaice	adult	442	0.05	3.6	0.59	0.38	0.97	0.68	0.53	0.92	0.71
GOA	Alaska skate	subadult	95	0.01	0.21	0.22	0.13	0.82	0.08	0.07	0.72	0.21
GOA	Alaska skate	adult	78	0.01	0.15	0.23	0.13	0.85	0.08	0.08	0.83	0.24
GOA	Aleutian skate	subadult	613	0.09	0.54	0.46	0.28	0.78	0.37	0.28	0.69	0.30
GOA	Aleutian skate	adult	147	0.02	0.19	0.24	0.17	0.83	0.15	0.12	0.77	0.25
GOA	arrowtooth flounder	early juvenile	1,825	0.23	--	--	--	0.79	0.58	0.53	0.71	--
GOA	arrowtooth flounder	subadult	7,390	0.87	276	0.35	0.64	0.70	0.92	0.93	0.88	0.28
GOA	arrowtooth flounder	adult	7,043	0.83	189	0.32	0.55	0.76	0.92	0.92	0.85	0.29
GOA	Atka mackerel	subadult	87	0.01	1.6	0.21	0.15	0.91	0.14	0.09	0.82	0.40
GOA	Atka mackerel	adult	700	0.08	143	0.10	0.33	0.85	0.31	0.36	0.77	0.35
GOA	Bering skate	subadult	401	0.06	0.33	0.37	0.27	0.84	0.28	0.27	0.76	0.28

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
GOA	Bering skate	adult	407	0.06	0.32	0.40	0.28	0.84	0.33	0.27	0.76	0.31
GOA	big skate	subadult	594	0.07	1.1	0.48	0.31	0.85	0.32	0.32	0.77	0.44
GOA	big skate	adult	195	0.02	0.20	0.29	0.19	0.86	0.15	0.15	0.80	0.27
GOA	butter sole	adult	881	0.10	30.1	0.47	0.46	0.93	0.61	0.55	0.85	0.54
GOA	Dover sole	subadult	3,710	0.44	17.4	0.51	0.61	0.83	0.78	0.73	0.75	0.46
GOA	Dover sole	adult	2,973	0.35	11.0	0.43	0.62	0.87	0.75	0.71	0.78	0.42
GOA	dusky rockfish	subadult	315	0.04	17.7	0.09	0.21	0.80	0.17	0.17	0.72	0.27
GOA	dusky rockfish	adult	1,061	0.14	53.1	0.23	0.40	0.83	0.40	0.47	0.76	0.28
GOA	English sole	early juvenile	56	0.01	--	--	--	0.99	0.89	0.22	0.95	--
GOA	English sole	subadult	116	0.01	2.3	0.28	0.20	0.95	0.30	0.20	0.90	0.57
GOA	English sole	adult	746	0.09	13.3	0.50	0.34	0.84	0.40	0.35	0.76	0.52
GOA	flathead sole	early juvenile	2,017	0.24	--	--	--	0.90	0.80	0.68	0.82	--
GOA	flathead sole	subadult	4,064	0.48	109	0.66	0.71	0.86	0.83	0.76	0.71	0.65
GOA	flathead sole	adult	4,201	0.49	63.3	0.60	0.72	0.88	0.87	0.79	0.75	0.54
GOA	giant octopus	all	459	0.05	0.33	0.24	0.20	0.75	0.16	0.20	0.70	0.15
GOA	greenstriped rockfish	adult	120	0.01	1.4	0.70	0.30	1.00	0.81	0.51	0.97	0.85
GOA	harlequin rockfish	subadult	102	0.01	14.6	0.26	0.16	0.92	0.18	0.11	0.84	0.50
GOA	harlequin rockfish	adult	514	0.06	71.3	0.50	0.31	0.88	0.33	0.33	0.80	0.44
GOA	longnose skate	subadult	1,058	0.12	0.63	0.24	0.28	0.74	0.25	0.34	0.67	0.15
GOA	longnose skate	adult	845	0.10	0.46	0.25	0.25	0.74	0.21	0.29	0.67	0.15

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
GOA	northern/southern rock soles	early juvenile	252	0.03	--	--	--	0.95	0.65	0.32	0.87	--
GOA	northern rock sole	subadult	1,854	0.24	57.3	0.58	0.68	0.96	0.85	0.79	0.88	0.68
GOA	northern rock sole	adult	1,980	0.25	25.0	0.46	0.68	0.95	0.85	0.79	0.88	0.58
GOA	northern rockfish	subadult	522	0.06	8.3	0.31	0.30	0.86	0.30	0.30	0.78	0.42
GOA	northern rockfish	adult	1,141	0.13	276	0.12	0.46	0.89	0.50	0.43	0.66	0.32
GOA	Pacific cod	early juvenile	354	0.05	--	--	--	0.95	0.76	0.40	0.88	--
GOA	Pacific cod	subadult	3,653	0.43	66.2	0.23	0.53	0.79	0.68	0.72	0.72	0.30
GOA	Pacific cod	adult	4,476	0.53	70.2	0.21	0.47	0.75	0.71	0.76	0.70	0.25
GOA	Pacific ocean perch	early juvenile	1,552	0.21	--	--	--	0.80	0.51	0.54	0.73	--
GOA	Pacific ocean perch	subadult	1,686	0.20	48.6	0.30	0.49	0.85	0.54	0.57	0.78	0.39
GOA	Pacific ocean perch	adult	2,992	0.35	692	0.35	0.65	0.81	0.60	0.57	0.48	0.39
GOA	Pacific sanddab	all	77	0.01	2.2	0.52	0.19	0.98	0.55	0.18	0.92	0.74
GOA	Petrale sole	subadult	59	0.01	0.32	0.30	0.18	0.98	0.28	0.14	0.92	0.56
GOA	Petrale sole	adult	271	0.03	1.3	0.54	0.29	0.96	0.57	0.38	0.90	0.65
GOA	pygmy rockfish	all	63	0.01	3.0	0.09	0.14	0.96	0.15	0.10	0.88	0.40
GOA	quillback rockfish	adult	73	0.01	0.44	0.34	0.17	0.96	0.35	0.13	0.90	0.51
GOA	redbanded rockfish	subadult	829	0.10	2.1	0.58	0.46	0.94	0.65	0.56	0.87	0.63
GOA	redbanded rockfish	adult	321	0.04	1.6	0.47	0.29	0.93	0.36	0.30	0.85	0.49
GOA	redstripe rockfish	subadult	133	0.02	7.2	0.24	0.20	0.95	0.42	0.18	0.88	0.52
GOA	redstripe rockfish	adult	234	0.03	47.9	0.54	0.25	0.94	0.44	0.24	0.85	0.65

Region	Species	Life stage	N	*Prev.*	RMSE	*r*	*ρ*	AUC	PR-AUC	F_1	*Acc.*	PDE
GOA	rex sole	early juvenile	480	0.06	--	--	--	0.85	0.33	0.31	0.77	--
GOA	rex sole	subadult	4,744	0.56	33.6	0.41	0.56	0.80	0.78	0.81	0.75	0.32
GOA	rex sole	adult	4,455	0.52	36.3	0.44	0.59	0.80	0.81	0.76	0.70	0.37
GOA	rosethorn rockfish	subadult	132	0.02	0.93	0.52	0.30	0.99	0.70	0.40	0.96	0.76
GOA	rosethorn rockfish	adult	186	0.02	2.5	0.72	0.40	0.99	0.75	0.50	0.96	0.82
GOA	rougheye blackspotted complex	subadult	2,178	0.26	20.4	0.60	0.62	0.90	0.76	0.69	0.81	0.57
GOA	rougheye blackspotted complex	adult	878	0.10	9.9	0.58	0.46	0.93	0.67	0.55	0.85	0.70
GOA	sablefish	early juvenile	959	0.13	--	--	--	0.84	0.54	0.44	0.75	--
GOA	sablefish	subadult	2,812	0.33	47.0	0.40	0.56	0.84	0.67	0.68	0.77	0.34
GOA	sablefish	adult	2,011	0.24	18.9	0.47	0.65	0.94	0.82	0.73	0.85	0.61
GOA	sand sole	adult	109	0.01	4.4	0.21	0.22	0.97	0.33	0.22	0.92	0.60
GOA	sharpchin rockfish	subadult	498	0.06	47.0	0.61	0.37	0.95	0.63	0.47	0.88	0.69
GOA	sharpchin rockfish	adult	425	0.05	97.9	0.26	0.34	0.95	0.53	0.40	0.87	0.54
GOA	shortraker rockfish	subadult	316	0.04	1.4	0.60	0.45	0.99	0.80	0.58	0.95	0.77
GOA	shortraker rockfish	adult	679	0.08	7.6	0.58	0.47	0.97	0.82	0.64	0.92	0.73
GOA	shortspine thornyhead	subadult	1,634	0.19	24.4	0.70	0.65	0.97	0.90	0.82	0.92	0.76
GOA	shortspine thornyhead	adult	1,998	0.23	44.4	0.78	0.70	0.96	0.89	0.81	0.90	0.82
GOA	silvergray rockfish	subadult	159	0.02	1.4	0.05	0.18	0.88	0.13	0.13	0.81	0.21
GOA	silvergray rockfish	adult	557	0.06	33.3	0.54	0.37	0.93	0.63	0.43	0.85	0.63

Region	**Species**	**Life stage**	**N**	***Prev.***	**RMSE**	***r***	***ρ***	**AUC**	**PR-AUC**	**F_1**	***Acc.***	**PDE**
GOA	slender sole	all	751	0.09	5.0	0.78	0.44	0.94	0.64	0.53	0.86	0.68
GOA	southern rock sole	subadult	2,213	0.28	30.2	0.57	0.71	0.94	0.86	0.80	0.88	0.64
GOA	southern rock sole	adult	2,772	0.36	22.1	0.58	0.76	0.94	0.89	0.83	0.87	0.64
GOA	spiny dogfish	subadult	1,262	0.15	10.3	0.34	0.41	0.83	0.43	0.47	0.75	0.45
GOA	spiny dogfish	adult	127	0.01	0.29	0.44	0.15	0.86	0.12	0.10	0.80	0.35
GOA	starry flounder	early juvenile	61	0.01	--	--	--	0.98	0.88	0.24	0.95	--
GOA	starry flounder	subadult	68	0.01	0.80	0.38	0.19	0.98	0.41	0.26	0.96	0.65
GOA	starry flounder	adult	604	0.07	13.3	0.38	0.43	0.96	0.73	0.57	0.90	0.59
GOA	walleye pollock	early juvenile	2,958	0.33	--	--	--	0.82	0.76	0.65	0.74	--
GOA	walleye pollock	subadult	4,599	0.54	298	0.23	0.40	0.70	0.69	0.72	0.59	0.21
GOA	walleye pollock	adult	4,351	0.51	237	0.17	0.49	0.74	0.70	0.69	0.55	0.23
GOA	yelloweye rockfish	subadult	79	0.01	0.17	0.49	0.16	0.92	0.21	0.10	0.85	0.39
GOA	yelloweye rockfish	adult	186	0.02	0.46	0.41	0.22	0.91	0.23	0.19	0.85	0.43
GOA	yellowfin sole	early juvenile	66	0.01	--	--	--	0.98	0.61	0.26	0.95	--
GOA	yellowfin sole	subadult	401	0.05	46.9	0.68	0.38	0.98	0.71	0.61	0.94	0.78
GOA	yellowfin sole	adult	491	0.06	58.0	0.71	0.40	0.98	0.71	0.64	0.94	0.79

6 ATTACHMENTS

Additional supporting documents are provided at attachments to this Discussion Paper and referenced herein to support evaluation of EFH component 1 in the 2022 EFH 5-year Review and specifically, for the February 2022 SSC meeting. Please refer to the electronic agenda[47] for this meeting to view and download the following attachments—

- **Attachment 1** is the Report of Stock Assessment Author Review of EFH Components 1 and 7 for the 2022 EFH 5-Year Review.
- **Attachment 2** is a collection of figures comparing 2017 and 2022 EFH areas as overlay maps, which is provided as a zipfolder with file names corresponding to the species' life stages where a comparison was possible (modeled in both 2017 and 2022).
- **Attachments 3-5** are three draft NMFS Technical Memoranda organized by the regions modeled by the Laman et al. study for the species life stages in the GOA and BSAI FMPs and the Crab FMP. Refer to the individual documents for region-specific methods and the full set of species' life stages results, including the new 2022 EFH maps showing the EFH area and percentile subareas (e.g., core EFH area used in the fishing effects analysis of the 2017 EFH 5-year Review). The three regional Technical Memoranda have been reviewed internally by NMFS and submitted to the NMFS publication process.
    - **Attachment 3:** Eastern Bering Sea (Laman et al. *in review*)
    - **Attachment 4:** Aleutian Islands (Harris et al. *in review*)
    - **Attachment 5:** Gulf of Alaska (Pirtle et al. *in review*)

[47] https://meetings.npfmc.org/Meeting/Details/2754